SYSTEM OPERATION ASSESSMENT OF LAKE WRIGHT PATMAN AND LAKE JIM CHAPMAN

Volume II – Appendices

JANUARY 2003

Prepared for:

U. S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Thomas C. Gooch, P.E.

Jon S. Albright

Andres Salazar, Ph.D

COE02291

Prepared by:

Freese and Nichols, Inc.
4055 International Plaza
Suite 200
Fort Worth, TX 76109
817/735-7300

SYSTEM OPERATION ASSESSMENT OF JIM CHAPMAN AND WRIGHT PATMAN LAKES

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2. US Army Corps of Engineers. Fort Worth District. *Cooper Lake, Sulphur River, Texas, Master Plan Design Memorandum No. 10*. May 1987.

3. Texas Parks and Wildlife Department. White Oak Creek Management Area. http://www.tpwd.state.tx.us/post_oak/wma/white_oak_creek/whiteoak_creek_index.htm

4. Fred Jensen, U.S. Army Corps of Engineers Fort Worth District, personal communication

5. U.S. Army Corps of Engineers Fort Worth District, *Jim Chapman Lake Cooper Dam Water Control Manual Chapter 7*, June 1999.

6. Freese and Nichols, Inc. et al., *Region C Water Plan,* January 2001.

7. Texas Natural Resource Conservation Commission, Water Rights database, available online at http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/permits.html#databases

8. U.S. Army Corps of Engineers Fort Worth District, available online at http://www1.swf-wc.usace.army.mil/pertdata/txkt2.pdf

9. U.S. Army Corps of Engineers New Orleans District, *Wright Patman Appendix I Master Reservoir Regulation Manual*, September 1974.

10. Texas Commission for Environmental Quality, Certificate of Adjudication 03-4836, issued to the City of Texarkana.

11. Contract DACW29-68-A-103, Between the United States of America and the City of Texarkana for Municipal and Industrial Water Supply Storage Space in Texarkana Reservoir, April 16, 1968.

12. Texas Water Development Board, *Volumetric Survey of Wright Patman Lake*, May 1997.

13. John C. Jones, Texas Parks and Wildlife Department, *Memorandum on Sulphur River Management Strategy,* July 30, 2002.

14. United States Geological Survey Water Quality Data for Texas. Available on line at http://waterdata.usgs.gov/tx/nwis/qw.

15. Environmental Protection Agency STORET Data. Available on line at http://www.epa.gov/STORET/.

Appendix B

Texas Parks and Wildlife Department Memorandums

OFFICE MEMORANDUM

TEXAS PARKS & WILDLIFE

COORDINATION-ROUTING			
ORG.	NAME	INITIAL	DATE
REMARKS:			
RETURN TO:			

TO: **Nathan Garner, Director**
Wildlife Region III

FROM: **John C. Jones**
Area Manager, CSIV

SUBJECT: **Sulphur River Management Strategy**

RE: **COE/FNI Proposal**

DATE: **July 30, 2002**

Nathan,

As per your instruction, I have discussed the Sulphur River management strategies as proposed by the COE and FNI with Carl Frentress, Kevin Kraai, Corey Mason and Perry Richardson. The information we present to you is a collaborative effort. It is our best guess of how this plan to increase the yield from the Sulphur River watershed would affect the Cooper and White Oak Creek WMAs. I will try to summarize our discussions and will attach some additional background information presented in more detail. I have also included a management scenario of the two-lake system for one annual cycle while working under ideal conditions with no limiting factors.

We all agree that the strategy proposed (as we know it) is a workable plan and much more acceptable than the alternative. It was necessary to make some assumptions based on the absence of what we considered to be pertinent factors:

- What will be the target increase in volume for each reservoir?
- What will be the duration of the water storage (hydroperiod)?
- What will be the dates of the increase (seasonality)?
- At what rate will the exchange take place?
- What acreage will be impacted?

Many of these questions will be answered only when the strategy is put into action but the answers may effect the results.

The White Oak Creek Wildlife Management Area is located up river from Patman Lake with an elevation difference of some 12 feet between the lowest control structure in the wetlands (242) and the proposed maximum conservation storage level (229). Because of this difference, we believe the proposed level changes in Patman lake operations should have minimal effect to this WMA. Also, the normal flood events that will occur are not expected to have greater impacts to the WMA when/if the operational level of Patman Lake is increased by the proposed amounts. Furthermore, if there is an increase in the in-stream volumes at White Oak Creek, we expect a beneficial result. This will enhance aquatic resources and, consequently, terrestrial fauna that utilizes them.

The conditions at Cooper WMA are decidedly different. Because the WMA is located on the shore of the lake where the level changes will occur, we suspect that it will be directly affected. The impacts will be greatest if the extra water is held for significant durations. If, however, the surplus water is pumped away in a timely fashion and not allowed to accumulate, subsequent impacts would be minimized.

Management Strategies

In general, we should continue to initiate and utilize strategies at our WMAs that maximize wetland functions and values. We can adopt a more flexible approach and therefore adapt our strategies to the conditions presented by the resource.

If water level fluctuations are reasonably predictable and/or controllable, we should continue to utilize moist-soil techniques.

- Drawdowns or de-watering to occur in spring to benefit migrating shorebirds
- Expose mud flats
- Capture seed production
- Promote annual plant growth for waterfowl food production
- Drawdowns in late summer to benefit fall migrating birds

If water levels trend toward higher elevations for longer durations, adopt strategies more consistent with permanent emergent marshes.

- Maintain water levels for increased wading bird usage
- Convert to more permanent marsh vegetation
- More controls for noxious vegetation
- Provide habitats for brooding and molting of waterfowl
- Provide waterfowl food

In reality, a combination of these techniques will most likely prevail.

Cooper Wildlife Management Area

Positive Effects

We believe that if pumping schedules permit, withdrawal of water from the Chapman Reservoir can be beneficial in:

- Encouraging extensive stands of annual plant species that produce foods for ducks. The potential exists for substantial acreage to be affected positively.
- Most desirable drawdown periods are early season (late January-early March)
- Mid-season (mid March – early May) drawdowns can produce excellent results when pest plants can be suppressed
- Mid-season drawdown would greatly benefit the Least Tern populations known to utilize the WMA for breeding and nesting activities.
- Rapid late summer drawdowns (August - mid-September) conducted in several increments produce mudflats that are used heavily by migrating shorebirds.

- Exposed mud flats provide excellent foraging areas for shorebirds before vegetative cover is too thick.

Negative Effects

If pumping schedules were not coordinated with wildlife management goals, we would lose our ability to perform the needed drawdowns. This would cause several negative events to occur:

- Increase the potential for encroachment of undesirable plants species.
- Increase our costs through advanced weed control efforts
- Longer hydroperiods would create an added expense burden through increased levee maintenance requirements.

Unacceptable Effects

- Excessively high water levels during the growing season (permanent flooding)
- Absence of some seasonal flooding
- Any additional storage above the conservation pool that directly floods bottomland hardwood forests during the growing season or has a negative impact to water table (Need to know how water table changes as a result of additional water storage in streams. A permanent rise in the local water table would damage trees.)
- Any actions resulting in damages to existing infrastructure is the responsibility of the COE. Our contract is to manage these Areas based on the existing lake management strategies.
- Any operational change that detracts from gains made in the habitats and infrastructure thus far.

White Oak Creek Wildlife Management Area

Positive Effects

- In-stream water levels will slightly increase
- Enhance aquatic resources and consequently benefit terrestrial fauna that use them

Negative Effects

- Impacts to water table unknown
- Damage to bottomland forests if water table permanently increases
- If the water level in the Sulphur River were increased to the extent that levels reach operational levels at the WMA wetland system, we would lose our ability to draw down water in our moist-soil units (primarily late winter to early spring).
- Significant increases in water levels for long durations would effect the integrity of our wetland infrastructure and add maintenance burden on the Department.

Unacceptable Effects

- Excessively high water levels during the growing season (permanent flooding)
- Absence of some seasonal flooding
- Any additional storage above the conservation pool that directly floods bottomland hardwood forests during the growing season or has a negative impact to water table (Need to know how

water table changes as a result of additional water storage in streams. A permanent rise in the local water table would damage trees.)

- Any actions resulting in damages to existing infrastructure is the responsibility of the COE. Our contract is to manage these Areas based on the existing lake management strategies.
- Any operational change that detracts from gains made in the habitats and infrastructure thus far.

Conclusion

As Carl writes, "the difficulty of developing management recommendations with a modest amount of information is prodigious. For this reason, we qualify our material with recognition that improvements and adjustments can be made in a continued spirit of optimizing fish and wildlife benefits as more specific useful information becomes available." However, we believe that we can manage these two WMAs without significant negative impacts while working in the strategy framework as presented to us. Open minds and dynamic management plans should prevail.

A Hypothetical Annual Management Plan for the Chapman - Patman Reservoir System

Jan. 1 – Chapman is at 440 feet elevation and Patman is at 228 feet. In mid-late January begin a slow draw down until late **April**. This could be accomplished by either pumping water to Lake Lavon (upstream) or by releasing water to flow through the system. Draw down continues until an elevation of 436 is reached.

This would yield: 1) annual plants for duck food production 2) expose mud flats for utilization by spring migrating shorebirds 3) provide breeding and nesting habitats for the Least Tern populations known to occur at the Cooper WMA.

Maintain the 436 elevation until **July**. At that time begin a moderate increase in water depths at Chapman with water from Patman to reach a maximum of 438 feet. The removal of water from Patman will expose mud flats that will be seeded, by air, with Japanese Millet to 1) prevent invasion of noxious plants and 2) provide a food source for wintering waterfowl.

Mid – late August – Chapman will initiate the first of two drawdowns (pumping or release). Each will be of about one foot in drop. The second will occur during **September** and concluded by **October 1** for a total water level change of 2 feet and thus back to the 436 elevation. This will provide habitat for fall migrating shore birds.

Thereafter, both reservoirs can re-fill to original elevations (Chapman – 440 and Patman – 228) and maintain that level until **January**.

D R A F T

Wright Patman/Cooper Reservoirs Water Exchange Project

Introduction:

Below are recommendations concerned with optimizing fish and wildlife benefits from a proposed water exchange process between Wright Patman and Cooper Reservoirs. Sites of concern include: Wright Patman Reservoir, Cooper Reservoir, White Oak Creek, Sulphur River, White Oak Creek Wildlife Management Area, and Cooper Lake Wildlife Management Area.

When initially contacted, we understood that: 1) substantial dynamics would occur in water levels such that a general increase would occur in the conservation pool storage in Wright Patman and a general decrease in Cooper, and, 2) the net effect in Cooper would be a drawdown during the growing season. We find this may not be the pattern. We contacted FNI. No information was provided other than they were waiting to receive recommendations from TPWD staff. We were told to provide water management recommendations that are beneficial to management for fish and wildlife. This task is complicated by several sectors for which we have no information. These unknowns of hydroperiod dynamics, include: 1) the magnitude of water level change (2) the duration of water level change, including storage and withdrawal (hydroperiod frequency), 3) dates of water level changes (hydroperiod seasonality), 4) rates of water level changes, and 5) acreage affected. We request that these points be considered as our recommendations are reviewed.

Management Strategies:

In this section, we describe management strategies that are employed to focus on wetlands or lands that simulate wetlands. In these strategies, we encourage manipulations of water levels that affect phenomena associated with wetland functions and values. These strategies address: 1) stream conditions, 2) moist soil management for waterfowl, 3) perennial emergent marshes, 4) combinations of #2 and #3, and 5) mudflats for shorebirds. Discussions of these points follow.

We believe increased water levels within the channels of the White Oak Creek and Sulphur River systems can be beneficial. Through nutrient cycles and food webs, improved conditions for aquatic biota also can generate benefits for terrestrial communities. We have some concerns that prolonged bank-full stream conditions can influence the water table sufficiently to cause widespread stress or mortality of trees in bottomland hardwood forests. In fact, this situation may result at some stream level threshold less than bank-full conditions. Therefore, we also offer some caution to the status of floodplain water tables even as we acknowledge the beneficial effects of increased flow in the stream channels. More information is needed about water table effects. Nonetheless, management to improve stream flow is useful.

Moist soil management involves an assemblage of techniques that simulate natural drawdowns during the growing season followed by shallow flooding during the dormant season. The desired outcome of this management approach is to encourage annual herbaceous plant communities that produce abundant seed yields that serve as available foods attractive to wintering dabbling ducks. In this methodology, seeds are captured in place for use as duck foods. Moist soil management is a dynamic strategy requiring annual assessments and applications of certain techniques that may vary each season.

Management for perennial emergent marshes can be less intense than moist soil management. Perennial emergent plant communities usually prosper when fluctuations of water levels are minimal in shallow wetlands. Some food production for wintering ducks can be achieved. However, these cover types are more important as brood and molting habitat for wood ducks, foraging habitat for wading birds and wetland-related mammals, breeding habitat for reptiles and amphibians, nursery habitat for fish, and a multitude of life requisites for aquatic invertebrates.

In many situations, opportunities exist to apply a combination of management techniques to produce a mosaic of cover types at a locale. This is a desirable outcome. It may have good potential along with stream maintenance in the proposed water exchange project.

Also, we consider that a native seedbank exists on-site for both annual and perennial plant species. Drawdowns during midsummer (July) are not recommended because of vulnerability to pest plants such as cocklebur and sumpweed. Artificial seeding of Japanese millet can be a viable contingency option in the event large expanses of mudflats are exposed during this inopportune period. Seeding rates of 15-20 pounds/acre on fresh mudflats can produce high yields of seed attractive to ducks. An approach akin to this is used on the Oklahoma portion of Lake Texoma.

Under management for both moist soil and perennial emergent communities, attention must be maintained for degradation of desired results by undesirable pest plants.

In addition to management activities that address stream resources of herbaceous plant communities, foraging habitat for shorebirds is produced by correctly timed dewatering of shallow wetlands. This is done to increase the amount of mudflats where shorebirds can find available invertebrates foods in the saturated soils or thin film of very shallow water. Shorebird migrations peak in this locale in late winter/early spring and during late summer/early fall. Exposure of mudflats during spring and late summer will be beneficial to shorebirds expected in this locale. This technique can be applied at both reservoirs.

Drawdowns to benefit shorebirds should be rapid and incremental. Several rapid decreases in water levels by about 6 – 12 inches can be used to lengthen the availability of food resources throughout the migration period. This incremental method is more favorable than one large decrease in water depth of more than 1-3 feet.

Positive Effects:

Wright Patman

At this time, we envision no significant undesirable effects from moderate increases in water levels in Wright Patman Reservoir. This assessment is given with the consideration that water levels will not be increased to the extent that adjacent stands of trees will be damaged.

Shallow flooding of the perimeter zone below the treeline is expected to promote plant communities typified by herbaceous perennial emergents and wetland shrubs.

Sulphur River, White Oak, and White Oak Creek WMA

We believe increasing the volume of water in the streams is desirable. This will benefit aquatic resources and, consequently, terrestrial fauna that utilize them. We speculate that the periodicity of natural floods can increase; this is generally beneficial as long as bottomland hardwoods are not damaged.

Cooper Lake/Cooper WMA

Withdrawal of water from Cooper during the growing season can be beneficial in encouraging extensive stands of annual plant species that produce foods for ducks. The potential exists for substantial acreage to be affected positively. The most desirable drawdowns are early season (late January – early March). Mid-season drawdowns (mid-March – early May) also can produce excellent results when pest plants can be suppressed.

Rapid late summer drawdowns (August – mid-September) that are conducted in several increments produce mudflats that are used heavily by migrating shorebirds. Also, shorebirds feed on mudflats in spring before vegetative cover is too thick. This benefit is consistent with early or midseason drawdowns conducted to encourage annual plants useful for producing duck foods.

Lowering water levels in Cooper Lake can allow moist soil management practices to be applied to the constructed wetland units on Cooper WMA. This is desirable, given that water is available for dormant season flooding.

Negative Effects:

Wright Patman Reservoir, Sulphur River, White Oak Creek,
White Oak Creek WMA

The effect of increased lake levels on associated water tables is unknown. Observations at some local sites where surface water remains pooled indicate that adjacent water tables can be raised. Mortality and stress on nearby trees is noted. The conclusion from these observations is that the water table is raised sufficiently to saturate the root zone, thus reducing or eliminating oxygen in the soil. Widespread occurrence of this situation could result in substantial negative impacts to bottomland hardwoods. More information is needed on the effects on water tables in order to predict acceptable increases in water levels.

We wish to note that the scope of management can involve many species and/or guilds of wildlife. Life requisites differ widely among these species. Therefore, negative effects may be realized for some species while benefits are generated for others. More specific management for target species or guilds can be prescribed as more information becomes available about the water management operations. This circumstance can be resolved with further dialog.

On White Oak Creek WMA, floodplain creeks and sloughs are influenced by water levels in White Oak Creek. When water levels in these streams reach elevations associated with water control structures on the created wetlands, discharge of water from the units would be hindered or prevented. This can have negative effects on the management activities at this site. Generally, discharges are necessary from late winter throughout the growing season. Additionally, the integrity of the levees at this site could be affected by excessive saturation from increased water levels. This can result in an added maintenance expense and manpower burden for TPWD. A contingency fund provided by the project sponsor is recommended in case this saturation condition is unavoidable.

Cooper Lake/Cooper WMA

The potential for growth of pest plants and/or encroachment of undesirable woody vegetation depends on the timing and duration of reductions in water levels.   This situation ultimately could prevail, especially in circumstances when efforts are made to conduct a combination of moist soil management in concert with maintenance of perennial emergent communities.

<u>Unacceptable Effects:</u>

1. Excessive permanent flooding during the growing season in all water bodies is considered unacceptable for the welfare of wetland-associated wildlife and habitats.

2. Seasonal flooding that is reasonably in accord with natural hydroperiods is desirable. Any operations that disrupt this beneficial pattern is considered unacceptable.

3. Any additional storage above the conservation pools of both reservoirs that directly floods adjacent forests during the growing season will have an unacceptable negative effect. Likewise, stream volume that causes root zone saturation via water table transport during the growing season is expected to result in unacceptable conditions.

4. At White Oak Creek WMA and Cooper WMA, any actions resulting in damage to existing infrastructure (especially levees and water control devices) will be unacceptable. Prevention of this situation or repair necessary from adverse water management operations should be considered the sole responsibility of the COE. Recognition should be made that the current TPWD contract is to manage these areas consistent with existing reservoir operations.

5. Any operational changes that detract from gains made thus far in wildlife habitat conditions and infrastructure improvements are considered unacceptable.

Conclusion:

The difficulty of developing management recommendations with a modest amount of information is prodigious. For this reason, we qualify our material with the recognition that improvements and adjustments can be made in a continued spirit of optimizing fish and wildlife benefits as more specific useful information becomes available.

Additionally, we wish to express our concern that these recommendations could be used to adversely affect natural resource conservation by rejecting a management plan for water exchange in favor of new reservoir construction. This outcome could have serious deleterious effects on further collaborative efforts in projects for water supply and fish and wildlife conservation. Therefore, continued efforts toward compatibility in the water exchange objectives for the existing reservoirs are encouraged.

Finally, recognition is made of the potential for this project to serve the goals and objectives of the respective integrated bird conservation plans and operations generated by the West Gulf Coastal Plain Initiative of the Lower Mississippi Joint Venture. This joint venture is a major endeavor that has evolved from the North American Waterfowl Management Plan. With the advent of the North American Bird Conservation Initiative, these activities now seek to integrate goals, strategies, and objectives from the respective national and regional plans for landbirds, shorebirds, and waterbirds. The application of this water management project to this large and important national bird conservation effort should not be overlooked.

Comments from U.S. Fish and Wildlife Service on Draft Report

Major impacts and issues that should be addressed during the assessment of reallocation for Wright Patman Lake:

1. Alteration of stream and riverine habitats, riparian areas, and wetlands by inundation.

2. Changes in water quality, including changes in sediment transport, dissolved oxygen, and water temperature.

3. Alteration of flow regimes, both increases and decreases, which make otherwise suitable riverine habitats unfit for aquatic invertebrates, fish, amphibians, and reptiles, and possibly, dependent riparian species.

4. Fluctuating in-stream flows and reservoir levels, which make habitats too unstable for full utilization and may degrade water quality.

5. Damage to terrestrial habitats and soils, disruption of runoff patterns related to pipeline.

6. Long-term changes in river hydrology, including possible changes in flow regime, the river's contribution to ground water, and evapotranspiration due to alterations of stream flow patterns that will have far reaching implications to fish and wildlife.

7. Evaluate the impacts of changed flow conditions on river form, aquatic habitat, the sequence of riffles and pools, lateral migration, and the bed material.

8. The modified storage and release of water from the reservoir may cause changes in the natural temperature conditions in the reach below the dam.

9. Impacts on threatened and endangered species: least tern and bald eagles.

10. A range of potential yields should be evaluated.

11. Project monitoring and adaptive management should be applied.

12. Adequate funding for monitoring and adaptive management should be obtained.

13. Alternatives analysis should focus on assessing impacts to both public and private property, e.g. the privately owned Bassett Creek area is known to be high quality bottomland hardwood habitat.

Comments from Texas Parks and Wildlife Department

White Oak Creek Meeting
Review of Draft Report on System Operation
October 24, 2002

Issues that should be addressed in the final report and may require additional studies:

1) Discuss influences of water table under a flat pool management system at ultimate curve water levels
2) What environmental studies should be implemented prior to a system management at ultimate curve levels
3) How will flooding regimes be affected (respond) with system management at maximum flat elevation (228.64).
4) Discuss the scope and values of an adaptive approach to environmental monitoring
5) Discuss the amount and types of vegetation that will be impacted by different flooding regimes, within the WMA, as well as upstream and downstream. This should be done at one foot contour levels
6) Discuss the effect on increased flow through the channel along the length of the project, will this increase erosion and scouring
7) Discuss the effect of all flow regimes on all habitat types, for the length of the project
8) Discuss the effect of different flow regimes on vegetation around the lakes as these are mitigation areas as well
9) Discuss what the possible impacts are to public use on the WMA

10) Please remember we are concerned with and required to comment on the project impact upstream and downstream of the WMA, as well as the impacts on the WMA. Any future studies should include that information as well.

From: Herb Kothmann [Herb.Kothmann@tpwd.state.tx.us]
Sent: Tuesday, November 12, 2002 11:39 AM
To: 'Jon Albright'
Cc: Rollin Macrae; Kathy Boydston; 'Carl Frentress'; 'Kevin Kraai'; 'John Jones'; Dennis Gissell; Tom Heger
Subject: RE: Patman/Chapman study

Jon -

My sole comment is the same one I voiced at the Waco meeting. We should minimize negative impact to public users of the habitats and wildlife that would result from the proposed actions.

Increased opportunity and improved access for water-related users is an anticipated positive result. However, I am primarily concerned about the extent of opportunity for terrestrial-related activities that will be lost. We should continue to offer at least the same amount of opportunity to each type of user group. Providing more waterfowl hunting and fishing opportunity at the cost of less opportunity for hunting squirrel and deer is not acceptable.

- Herb

Freese and Nichols, Inc. Engineers Environmental Scientists Architects
4055 International Plaza, Suite 200 Fort Worth, Texas 76109 817 735-7300 817 735-7491 fax www.freese.com

December 13, 2002

Kathy Boydston
Carl Fentriss
Nathan Garner
Dennis Gissell
Tom Heger
John Jones
Herb Kothmann
Kevin Kraai
Cindy Loeffler
Rollin MacRae

Texas Parks and Wildlife Department

Re: Second Draft System Operation Assessment of Lake Wright Patman and Lake Jim Chapman

Thank you for taking time to review the October 2002 *Draft System Operation Assessment of Lake Wright Patman and Lake Jim Chapman.* Unfortunately, the comments in your November 18 memorandum are beyond the scope of the current study and cannot be addressed in the final report. A synopsis of your comments has been added to the conclusions section of the second draft report (Chapter 6) as suggestions for additional studies. Please review this section to see if it covers your concerns.

We are sending you a second draft of the study on CD ROM. Chapters 4 and 5 of the second draft have been largely rewritten. If you have time, we would appreciate your comments on these chapters specifically and the rest of the report in general. However, please keep in mind that this particular study is complete and is in the report stage. Additional analyses will need to be undertaken in future studies.

Please call me at (817) 725-7267 if you have any questions or comments.

Sincerely,

Jon S. Albright

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Appendix C

Detailed Modeling Approach

APPENDIX C
MODELING APPROACH

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Appendix C
Modeling Approach

C-1.0 Introduction

This appendix is a detailed presentation of the modeling approach for the System Operation Assessment of Wright Patman and Jim Chapman Lakes, Corps contract DACW63-01-D-0001. The assessment relies on a custom model developed specifically for this project. The model is coded in Digital Visual FORTRAN version 5.0A. Output from the model consists of tab-separated data files that can be imported into Excel or other programs for further analysis. The model uses a daily time step and also uses adjusted historical hydrology from 1940 through 2001. Components of the model include:

- Operation of Lake Jim Chapman and Lake Wright Patman, including reservoir content, inflows, spills and releases, evaporative losses and reservoir demands
- Flows between the reservoirs at the South Sulphur near Cooper gage, the Sulphur River near Talco gage, and the downstream edge of the White Oak Creek Wildlife Management Area (WMA)
- Delivery of water from Lake Wright Patman to Lake Jim Chapman

The model is capable of simulating a variety of operational policies designed to increase the overall yield of the two reservoirs. The criterion for success of a proposed set of operational policies is the increase in yield of the system when compared to current operation policies.

As part of the modeling approach, we changed the Scope of Services so that the impact on the White Oak Creek WMA is evaluated at the U.S. Highway 67 bridge a few miles upstream. This recommendation is discussed in the sections on flow routing between Lake Jim Chapman and the impact on the White Oak Creek WMA.

The remainder of this appendix gives detailed explanation of the components and procedures used in the model.

C-2.0 Hydrology

C-2.1 Runoff

This section describes the approach for developing daily inflows for use in the System Operation Assessment of Wright Patman and Jim Chapman Lakes. Daily inflows were developed from available data, covering the period from 1940 to 2001. There were three sources of data evaluated for use in this study:

- Flows derived from the Sulphur Basin Water Availability Model (WAM),
- Freese and Nichols flows developed in previous studies, and
- Corps flows used in the SUPER Model.

This memorandum describes the flows, presents a comparison of the flows, and recommends an approach for developing flows for the study.

C-2.1.1 Description of Flows

Sulphur WAM Flows

The Sulphur Basin Water Availability Model study was sponsored by the Texas Natural Resource Conservation Commission (TNRCC) as part of statewide water planning under Senate Bill One. Senate Bill One directed TNRCC to create water availability models for each basin in Texas except the Rio Grande for use in water rights allocation and planning. The WAM uses the Water Rights Analysis Package (WRAP), a model developed by Dr. Ralph Wurbs of Texas A&M University specifically to model Texas water rights under the prior appropriations doctrine. Input data sets and other pertinent information are available in the WAM report for the Sulphur Basin[1]. The Sulphur Basin study covers the period from 1940 to 1996.

The WRAP model uses monthly naturalized flows to allocate water to water rights based on geographic location, permitted diversion amount and priority. Naturalized flows are historical flows that have been adjusted to remove the impact of historical diversions, return flows and reservoir depletions. For the Sulphur WAM, naturalized flows were developed at the five control points listed in Table C-1. The WRAP model distributes the flows to the diversion locations of each individual water right using a methodology based on the U.S. Natural Resources Conservation Service (NRCS) curve number method. Further information on this method may be found in the WRAP documentation[2].

Table C-2 gives information on how flows were derived at the two subwatersheds of primary interest: the South Sulphur River at Cooper, which is downstream of Lake Jim Chapman, and the Texas-Arkansas state line, which is downstream of Lake Wright Patman.

Table C-1
Naturalized Flow Locations in the Sulphur WAM

WAM Subwatershed	USGS Station Number	Station Name
A	7342500	South Sulphur River near Cooper
B	7343000	North Sulphur River near Cooper
C	7343200	Sulphur River near Talco
D	7343500	White Oak Creek near Talco
E	7344000	Sulphur River near Darden
F		Texas-Arkansas state line

Table C-2
Summary of Methodology Used to Calculate WAM Flows

Control Point	Period	Method
South Sulphur River near Cooper	1/40 to 5/42	Correlation with the White Oak Creek below Talco gage (7343800)
	6/42 to 12/96	Naturalization of gage flow
Texas/Arkansas state line	Jan 1940-Dec 1956	Calculation of incremental flows from naturalized flows at the Sulphur River near Darden using the drainage area ratio method
	Jan 1961 – Dec 1965 Jan 1968 – Dec 1977 Oct 1979 – Dec 1996	Calculation of incremental flow based on mass balance inflows into Lake Wright Patman less flow at the Sulphur River near Talco and White Oak Creek near Talco gages with a delay of 4 days
	Jan 1957 – Dec 1960 Jan 1966 – Dec 1967 Jan 1978 – Sep 1979	Calculation of incremental based on naturalized flow at the Sulphur River near Talco and White Oak Creek near Talco gages using the drainage area ratio method

For this study, the reservoir inflows were derived from a modified version of Run 3, one of the standard runs in the Sulphur WAM report. Run 3 assumes full diversions for all water rights and no return flows from either surface water or groundwater use. Table C-3 gives a list of the water rights in the Sulphur WAM.

Table C-3
Sulphur Basin Water Rights Used in the Sulphur WAM

Water Rights above Jim Chapman Lake

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4795_1	69	MUN	1925-12-31	425	CITY OF WOLFE CITY
4795_2	232	MUN	1957-08-12	855	CITY OF WOLFE CITY
4796_2	0	IRR	1983-04-18	60	WEBB HILL COUNTRY CLUB
4796_1	80	IRR	1968-03-11	39	WEBB HILL COUNTRY CLUB
Total	381				

Water Rights in Jim Chapman Lake

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4797BI	0	IND	1965-11-19	310000	CITY OF COMMERCE
4797BM	0	MUN	1965-11-19	310000	CITY OF COMMERCE
4799I	9,180	IND	1965-11-19	310000	CITY OF IRVING
4797AI	11,560	IND	1965-11-19	310000	SULPHUR RIVER MWD
4797AM	26,960	MUN	1965-11-19	310000	SULPHUR RIVER MWD
4799M	44,820	MUN	1965-11-19	310000	CITY OF IRVING
4798	54,000	MUN	1965-11-19	310000	NORTH TEXAS MWD
Total	146,520				

Water Rights in the Sulphur River between Jim Chapman and the downstream end of White Oak Creek WMA

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4804	10,000	IND	1952-03-06	7100	TEXAS UTILITIES ELECTRIC CO
4803_1	650	IRR	1978-06-19	328	HELMUT HERMANN ET AL.
4803_2	350	IRR	1978-06-19	0	HELMUT HERMANN ET AL.
4803_3	900	IRR	1982-11-15	0	HELMUT HERMANN ET AL.
4802	278	IRR	1955-12-31	300	ALEXANDER FRICK ET AL.
4148	2,828	IRR	1981-09-14	3875	SARA M DUNHAM TRUST
4805_1	0	IRR	1981-01-05	186	E.P. LAND AND CATTLE CO., INC.
4805_2	0	IRR	1981-01-05	1307	E.P. LAND AND CATTLE CO., INC.
4805_3	2,500	IRR	1981-01-05	1307	E.P. LAND AND CATTLE CO., INC.
4805_4	500	IRR	1981-01-05	756	E.P. LAND AND CATTLE CO., INC.
Total	18,006				

(Table C-3 Cont.)

Water Rights in tributaries between Jim Chapman and the downstream end of White Oak Creek WMA

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4800	273	MUN	1977-01-03	164	CITY OF COOPER
4395	1,518	MUN	1983-09-06	4890	CITY OF COOPER
4205	102	MUN	1982-04-26	152	CITY OF PECAN GAP
5200	0	REC	1988-11-01	394	GORDON COUNTRY CLUB
4801	5	IRR	1979-07-02	34	DELTA COUNTRY CLUB
4148B	11,312	IRR	1997-04-11	2925	SARA M DUNHAM TRUST
4148A	5,500	IRR	1984-11-07	3623	SARA M DUNHAM TRUST
4813	113	IRR	1975-12-15	127	SULPHUR SPGS COUNTRY CLUB
4812_1	0	MUN	1975-12-01	408	CITY OF SULPHUR SPRINGS
4812_2	408	MUN	1985-02-12	408	CITY OF SULPHUR SPRINGS
4811_3	0	MUN	1970-11-30	16260	SULPHUR SRINGS WATER DIST
4811_4	0	MUN	1983-09-26	17838	SULPHUR SRINGS WATER DIST
4811_1	2,000	MUN	1951-07-24	2100	SULPHUR SRINGS WATER DIST
4811_2	7,800	MUN	1968-11-25	14000	SULPHUR SRINGS WATER DIST
4819	0	OTH	1974-03-18	2360	DDC PROPERTIES CO.
4818	11	IRR	1964-12-31	24	ROBERT W CAMPBELL ET AL.
4817	333	IRR	1964-06-30	0	HANS WEISS ET UX.
5392	341	IRR	1991-12-06	0	PAUL A PIEFER ET UX,
4816_1	188	MUN	1976-03-01	434	CITY OF MOUNT VERNON
4816_2	212	MUN	1982-11-22	434	CITY OF MOUNT VERNON
4815	0	OTH	1976-03-28	760	CHARLES HELM & LEWIS HELM
4814	30	IRR	1959-07-16	26	JERRY JORDAN TRUSTEE ET AL.
5150	0	MUN	1987-07-28	269	LARRY MILES ET AL.
5510	0	IND	1995-01-03	172	TEXAS UTILITIES MINING CO.
5285	0	IND	1990-02-20	125	TEXAS UTILITIES MINING CO.
4822	100	IRR	1967-07-31	196	JOHN E BERNICE BALDWIN
4821	1	IND	1953-12-31	1	ANNA P LEWIS
5562_1	9	IND	1996-11-19	0	TEXAS UTILITIES MINING CO.
5562_2	79	IND	1996-11-19	0	TEXAS UTILITIES MINING CO.
4820	22	IRR	1964-12-31	0	BILLY J MAXTON
5562_3	37	IND	1996-11-19	0	TEXAS UTILITIES MINING CO.
4810	200	IRR	1960-04-04	200	PERRY R BASS INC
4809I	1	IND	1964-01-20	1225	RED RIVER COUNTY WCID
4809M	1,120	MUN	1964-01-20	1225	RED RIVER COUNTY WCID
4808	0	OTH	1975-01-06	670	RED RIVER COUNTRY CLUB
4807	22	IRR	1969-09-22	75	MARY MARGARET VAUGHAN
4806	8	IRR	1969-09-22	75	MARY MARGARET VAUGHAN
4828	0	REC	1973-01-29	500	GLASS CLUB LAKE, INC.
4827_1	0	OTH	1974-10-18	796	BROVENTURE COMPANY, INC.
4827_2	0	OTH	1974-10-18	659	BROVENTURE COMPANY, INC.
4825	20	IRR	1963-12-31	30	ROBERT COOKS ET AL.
4826	0	OTH	1973-01-08	151	ELLIS-KELLY LAKE CLUB
4823	23	IRR	1965-06-01	24	ARDELIA GAUNTT
4824	8	IRR	1965-06-01	0	WALTER W LEE
4838	0	REC	1975-11-17	52	INTERNATIONAL PAPER CO.
Total	31,796				

(Table C-3 Cont.)

Water Rights in tributaries between White Oak Creek WMA and Wright Patman Lake

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4831	31	MUN	1914-06-30	259	CITY OF NEW BOSTON
4830	378	IRR	1940-04-30	0	WILLIAM E JOHNSON JR. ET AL.
4834	39	IRR	1940-04-30	15	WILLIAM E JOHNSON JR. ET AL.
4829	4	IRR	1940-04-30	0	WILLIAM E JOHNSON JR. ET AL.
5449ON	863	OTH	1993-02-18	504	TEXAS PARKS AND WILDLIFE DEPT
5449OC	0	OTH	1993-02-18	1367	TEXAS PARKS AND WILDLIFE DEPT
4835	0	REC	1948-12-31	78	JERRY PRATHER ET UX
4833	8	IND	1956-02-01	13.8	H.C. PRANGE JR.
4832	325	MUN	1944-08-29	8	CITY OF NEW BOSTON
Total	1,648				

Water Rights in Wright Patman Lake

Water Right Identifier	Diversion (ac-ft/year)	Use	Priority Date (yyyy-mm-dd)	Storage (ac-ft)	Owner
4836M	45,000	MUN	1951-03-05	386900	CITY OF TEXARKANA
4836I	135,000	IND	1957-02-17	386900	CITY OF TEXARKANA
Total	180,000				

Run 3 was chosen for two reasons:

- Run 3 gives a conservatively low value for available flow because it assumes that all water rights are used to their full extent and no water is available from return flows.
- Run 3 is one of the two runs used by TNRCC when evaluating applications for new water rights diversions. (The second run, Run 8, is a ‘current conditions’ run.)

We made the following modifications to Run 3 for the purpose of developing inflows for this study:

- The setup was modified to run with the July 2001 version of the WRAP model. The original study was performed with an earlier version of the WRAP model. The latest version has some improvements in the calculations that result in slightly different values than the older version.
- Flows are distributed from primary control points to diversion locations using the drainage area ratio method rather than the NRCS method. In the opinion of Freese and Nichols, the drainage area ratio method is more appropriate for this type of study.
- The water rights associated with Lake Jim Chapman and Lake Wright Patman have no diversion or storage. This gives flows at the Lake Jim Chapman and Lake Wright Patman dam sites that are equivalent to having all other water rights in the Sulphur Basin diverting at their full permitted use without the impact of either reservoir.

We extracted flows at the Lake Jim Chapman and Lake Wright Patman dam sites from the modified Run 3 output. There are two categories of flow in the model output that are of interest to the current study:

- *Regulated flows*, which are the flows that occur at the dam site after upstream water rights have been diverted, and
- *Unappropriated flows*, which are the flows available for diversion and impoundment in the reservoirs.

The difference between the regulated and unappropriated flows is the amount that needs to be passed downstream for other water rights.

There is very little difference in regulated and unappropriated flows at the Lake Jim Chapman dam site. Unappropriated flows equal regulated flows for 490 out of the 684 months in the simulation. For Lake Wright Patman, unappropriated flows are equal to regulated flows for the entire simulation because there are no water rights in Texas directly downstream of the reservoir.

Using this method, the flows at the Lake Wright Patman dam site are the total flows from the entire basin, including water originating above Lake Jim Chapman. To get the incremental flows below Lake Jim Chapman for direct comparison with flows from other sources, the Lake Jim Chapman flows are subtracted from the Lake Wright Patman flows.

The Sulphur WAM uses a monthly time step, while the current study requires a daily time step. If WAM flows are used, they will need to be distributed to the days in the month. The most common method of performing this type of distribution is to use daily flows at a nearby gage or some other nearby source. The daily flows are converted to a percentage of total flow during each month. The monthly flows are then distributed to each day using these percentages.

The advantages of using flows derived from the Sulphur WAM are:

- The results will be compatible with the TNRCC permitting process. Implementing system operation for Lakes Wright Patman and Jim Chapman may require a change in water rights and using the WAM may facilitate that process.
- The flows fully account for existing water rights.
- Flows may be derived at all locations of interest for the system operation assessment.

The disadvantages of using WAM flows are:

- The flows are only available on a monthly basis, not a daily basis.
- The flows may not be compatible with other Corps flow data.
- Flows are only available from 1940 to 1996. The flows would need to be extended through 2001 to cover the entire study period.

Freese and Nichols (FNI) Flows

Freese and Nichols has calculated flows in the Sulphur Basin for several previous studies. The FNI inflows cover the period from 1941 to 1990 for Lake Jim Chapman and from 1941 to 1986 for Lake Wright Patman. Both series are only available in a monthly step. Flows have been adjusted to account for major water rights between the two reservoirs. Table C-4 summarizes the method used to calculate the FNI flows. Note that the FNI flows depend entirely on gaged flows.

FNI used the Sulphur River near Darden gage rather than the White Oak Creek below Talco gage to fill in data prior to establishment of the South Sulphur River near Cooper gage in 1942. The records for the White Oak Creek gage are poor and were considered to be less accurate than the Darden gage.

Table C-4
Summary of Methodology Used to Calculate FNI Flows

Reservoir	Period	Method
Lake Jim Chapman	Jan 1941 - May 1942	Sulphur River near Darden multiplied by the drainage area ratio of the reservoir to the gage
	June 1942- Dec 1990	South Sulphur River near Cooper multiplied by the drainage are ratio of the reservoir to the gage
Lake Wright Patman	Jan 1941- Dec 1956	Sulphur River near Darden multiplied by the drainage area ratio of the reservoir to the gage less flows above Lake Jim Chapman
	Jan 1957 - Dec 1986	Sulphur River near Talco plus White Oak Creek near Talco multiplied by the drainage area ratio of the reservoir to the gages less flows above Lake Jim Chapman

The original FNI flows for Lake Wright Patman included theoretical spills and releases from Lake Jim Chapman. For the purpose of this analysis, these spills and releases have been subtracted from the flows so that the flows would be compatible with the modeling approach.

The advantages of the FNI flows are:

- The derivation of the flows is completely documented in FNI files.
- The calculation method is straightforward and not as complex as the WAM method.
- Because the flows are calculated using gage data they can be extended fairly easily through 2001.

The disadvantages of the FNI flows are:

- Conversion to daily flows may require an analysis of flow timing to adjust for the construction of Lake Jim Chapman.
- Flows are not available at all points of interest to the study.

Corps SUPER Model Flows

The Corps provided flows for Lake Jim Chapman and Lake Wright Patman from the SUPER model for the period from 1938 to 2001. The series are complete except for the Lake Jim Chapman flows from January 1991 to November 1991. Because the missing data is prior to the closing of Lake Jim Chapman dam, the missing data may be easily calculated using gage data. The SUPER model is a daily-time step model that has been used for more than 30 years by the Corps for flood control and reservoir yield analyses. The method used to compute the flows was not provided, but they appear to be primarily based on gage data for Lake Jim Chapman and a mass balance of Lake Wright Patman.

The WAM has a somewhat different approach than the Corps when deriving reservoir inflows using the mass balance technique. The WAM flows have estimates of precipitation on the reservoir removed from the inflow calculations. Standard Corps methodology does not estimate and remove precipitation directly on the reservoir[3]. The Corps method more accurately accounts for precipitation on the reservoir than estimating precipitation based on rain gage data. In general, the Corps method is sound as long as it is taken into account when developing net evaporation rates for use in a model. However, if in the modeling process the reservoir elevation is substantially different from what it was historically, inflows calculated using the Corps method are not as appropriate as inflows that remove the effect of direct precipitation on the lake. In this study, the operation of Lake Wright Patman was substantially different than it was historically.

The advantages of the Corps flows are:

- The flows are available on a daily basis for almost all of the period covered in this study.
- They are compatible with other Corps work.

The disadvantages of the Corps inflows are:

- The Corps flows do not take into account diversions by other water rights, which will be important in the permitting process.
- The flows are not appropriate for operational scenarios that result in a substantially different elevation of the reservoir than occurred historically.

C-2.1.2 Comparison of Flows

Figures C-1 through C-24 are series of graphs comparing the WAM flows, FNI flows and SUPER model flows. In order to directly compare daily SUPER model flows to the monthly WAM and FNI flows, the SUPER model flows were summed on a monthly basis and converted into acre-feet.

<u>Comparison for Lake Jim Chapman</u>

Figures C-1 through C-12 are comparative charts of the WAM, FNI and SUPER model flows for Lake Jim Chapman. All series are very similar to each other after June 1942. Differences before that exist as the result of different assumptions for filling-in missing data prior to starting the operation of the gage in the South Sulphur River near Cooper, downstream of Jim Chapman (USGS 7342500). The WAM used the White Oak Creek below Talco gage, while FNI used the Sulphur River near Darden gage because of the poor quality of the White Oak Creek gage records. The source of the Corps inflows was not provided.

Figure C-1.1
Unappropiated WAM flows (Run 3) and FNI flows (1941-1965)
Lake Chapman

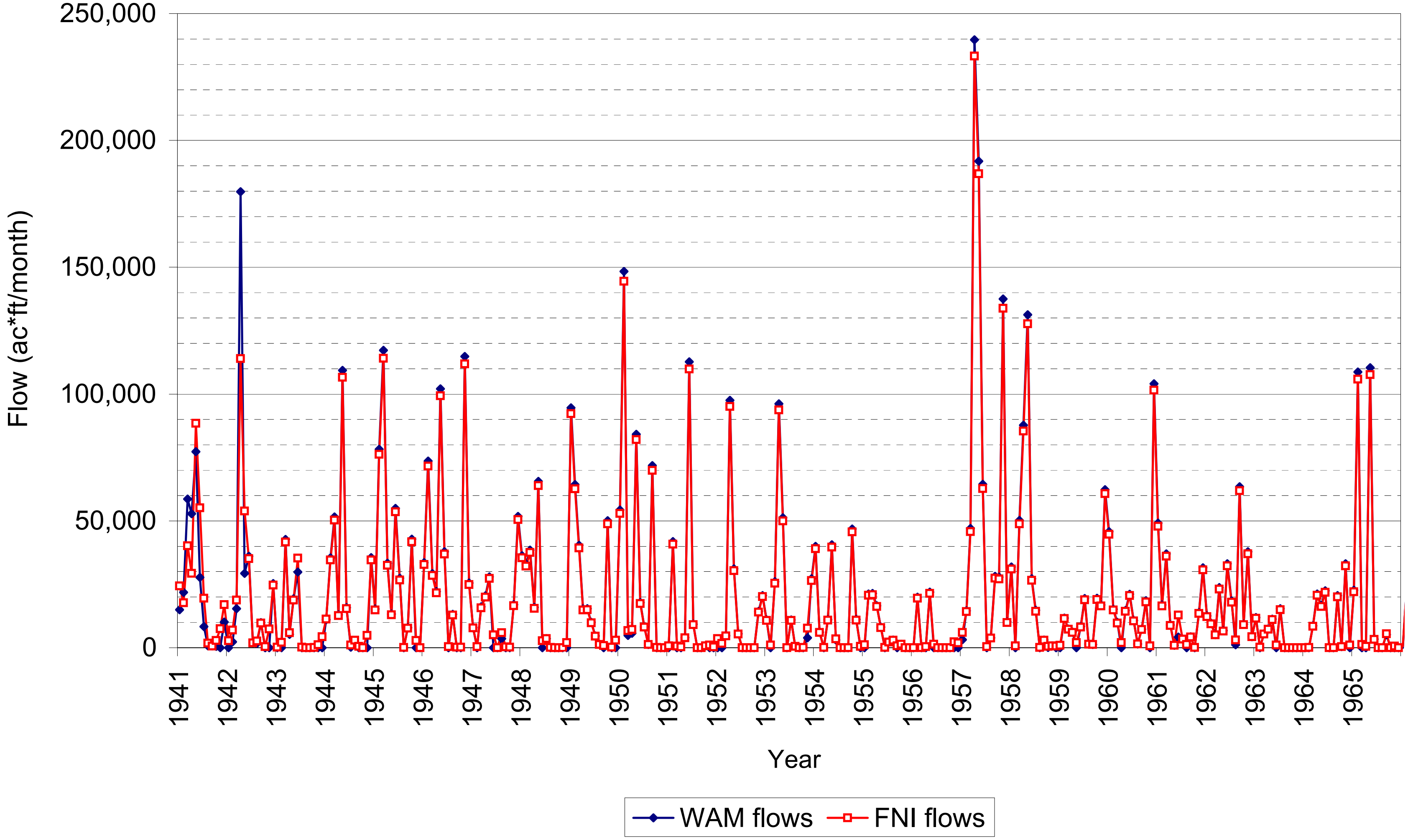


Figure C-1.2
Unappropiated WAM flows (Run 3) and FNI flows (1966-1990)
Lake Chapman

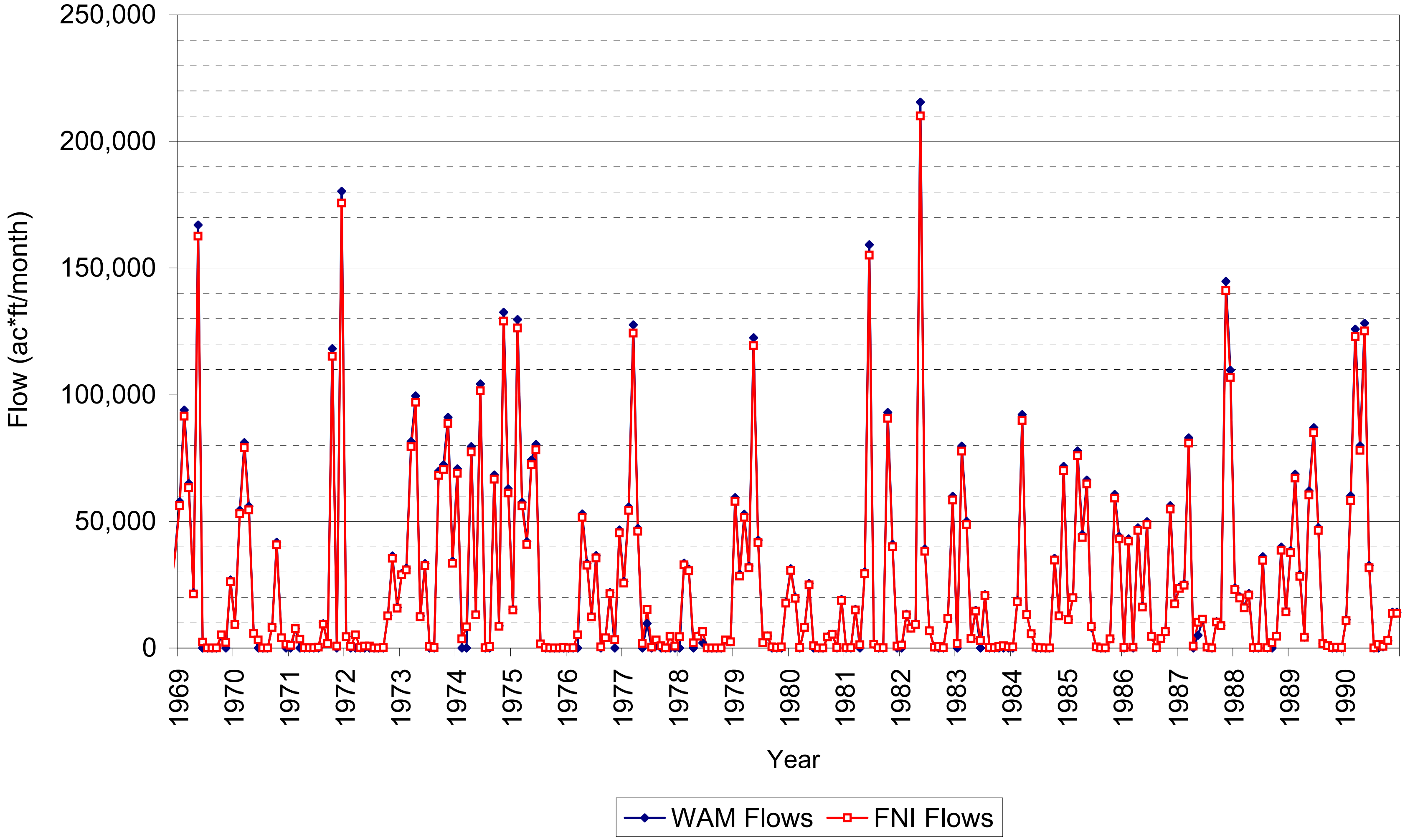


Figure C-2
Difference unappropiated WAM flows (Run 3) and FNI flows
Lake Chapman

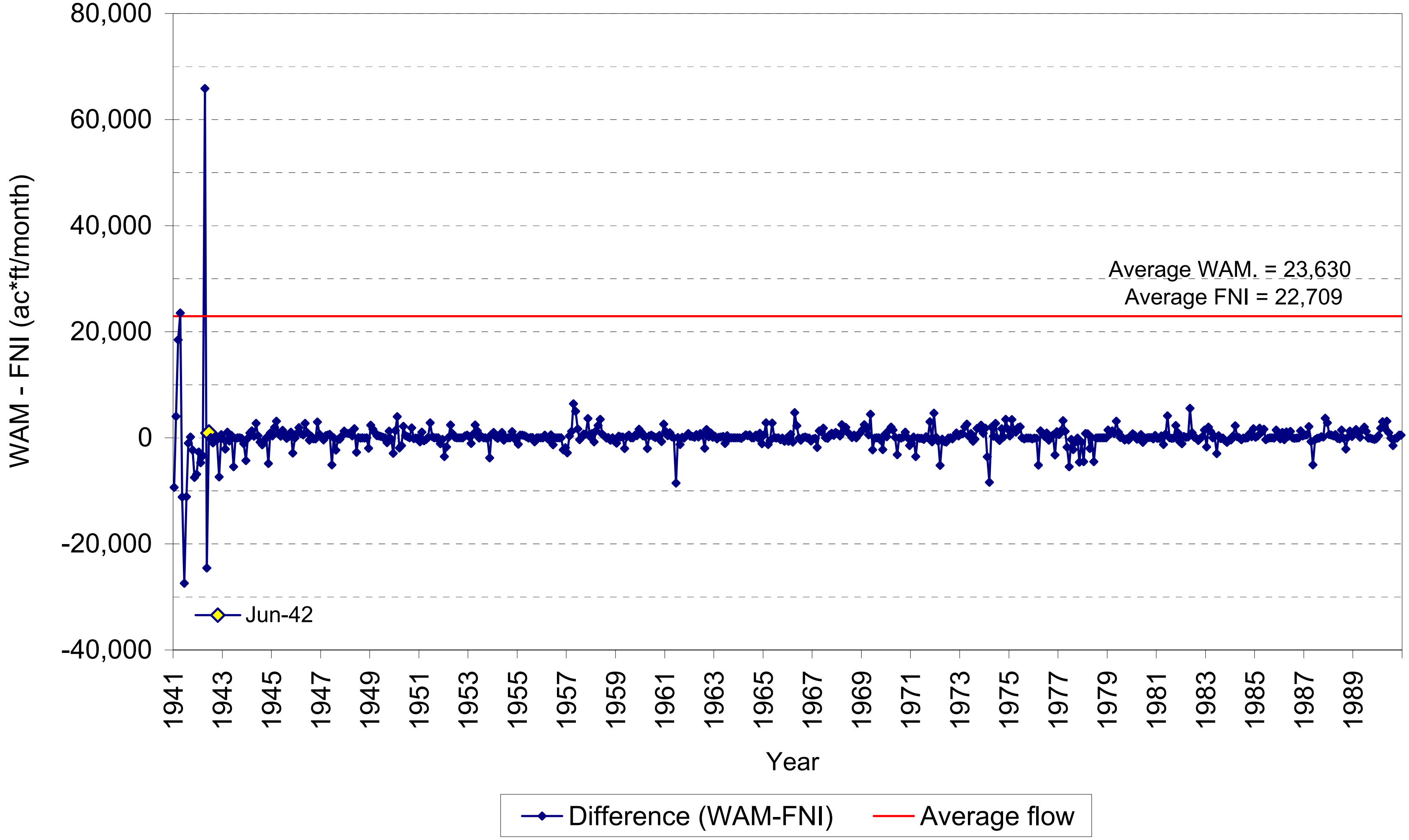


Figure C-3.1
Unappropiated WAM flows (Run 3) and FNI flows (Jun 1942-Dec 1990)
Lake Chapman

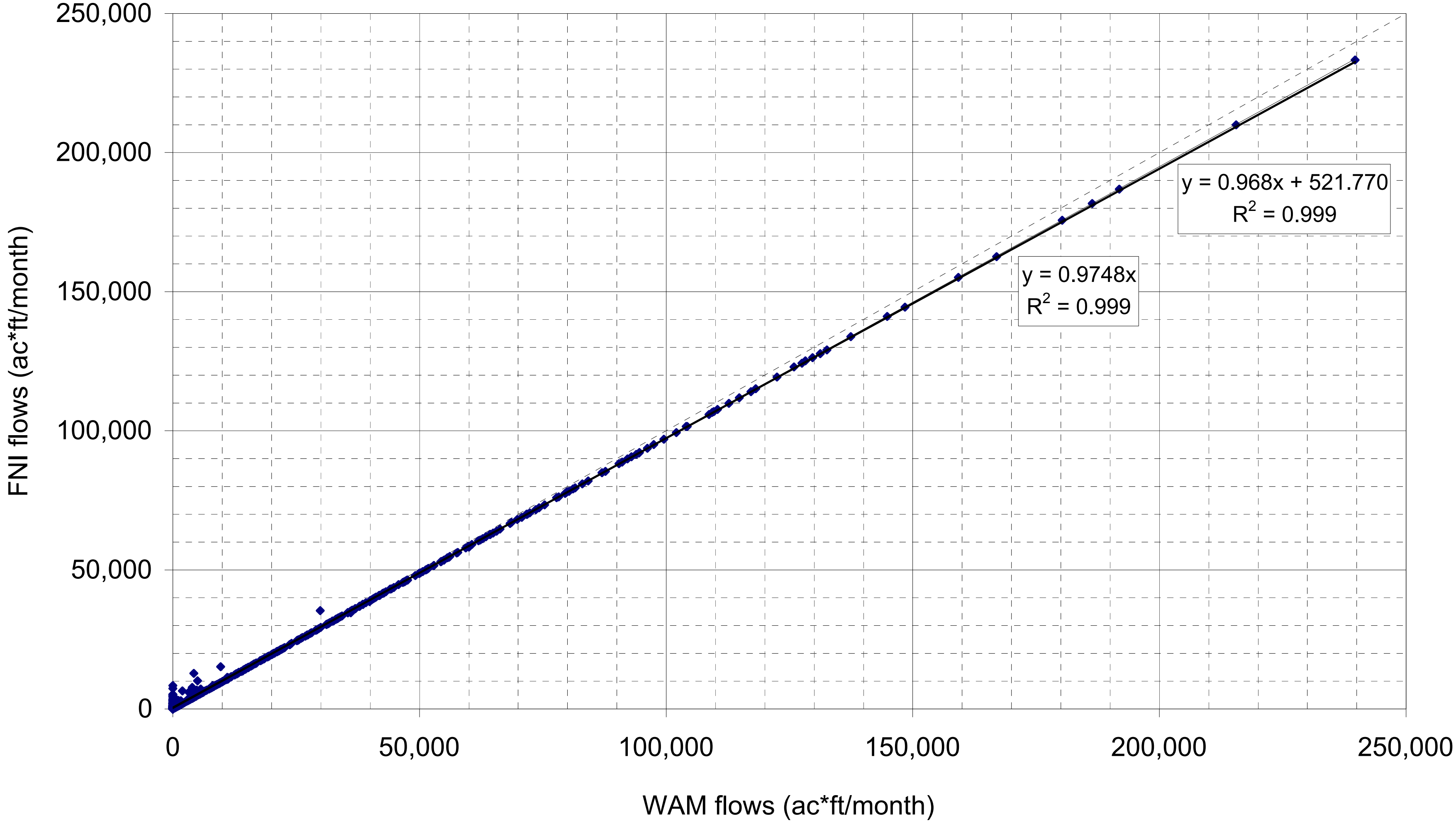


Figure C-3.2
Unappropiated WAM flows (Run 3) and FNI flows (Full overlap period 1941-1990)
Lake Chapman

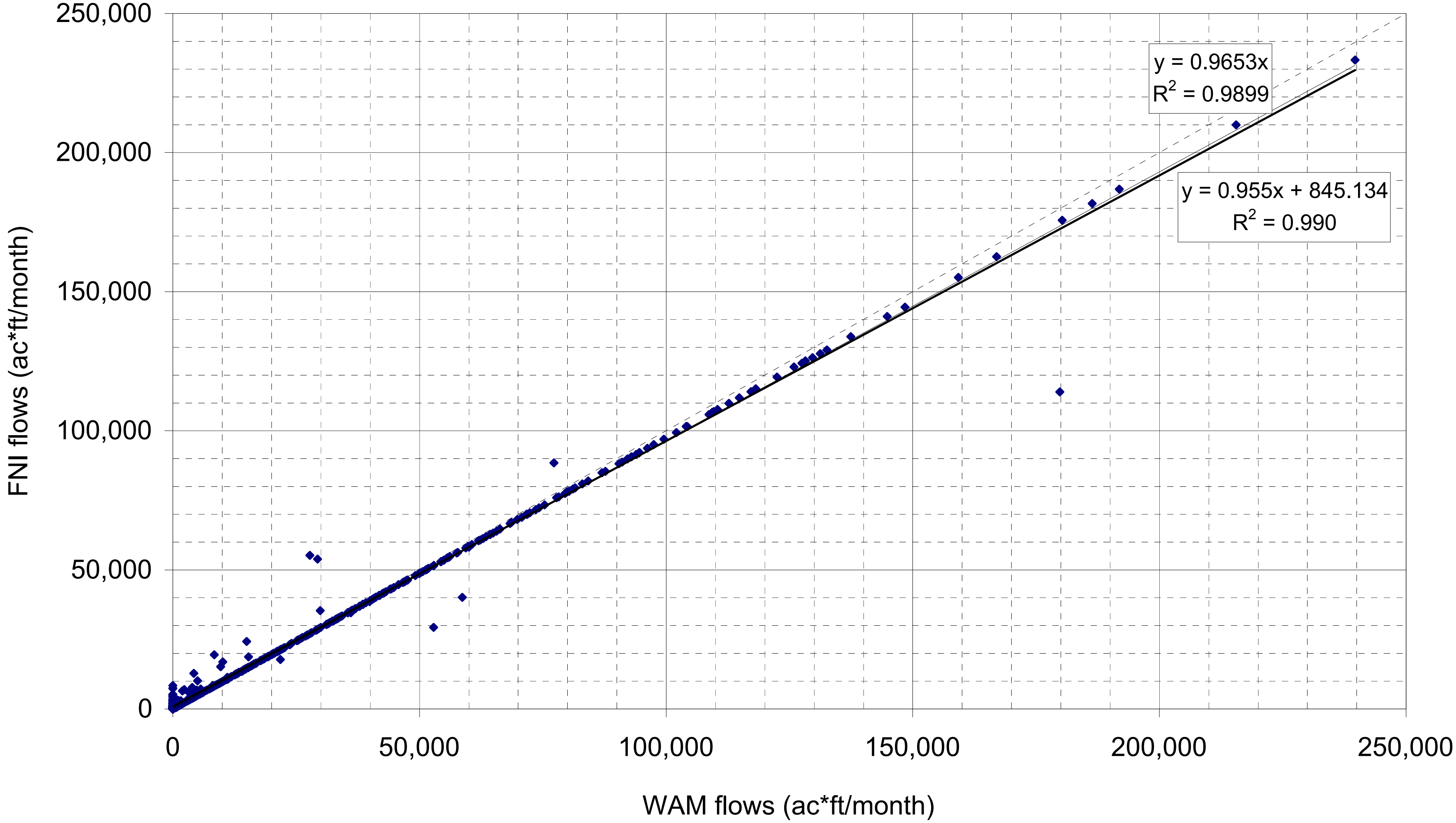


Figure C-4
Double mass curve unappropiated WAM flows (Run 3) and FNI flows (1941-1996)
Lake Chapman

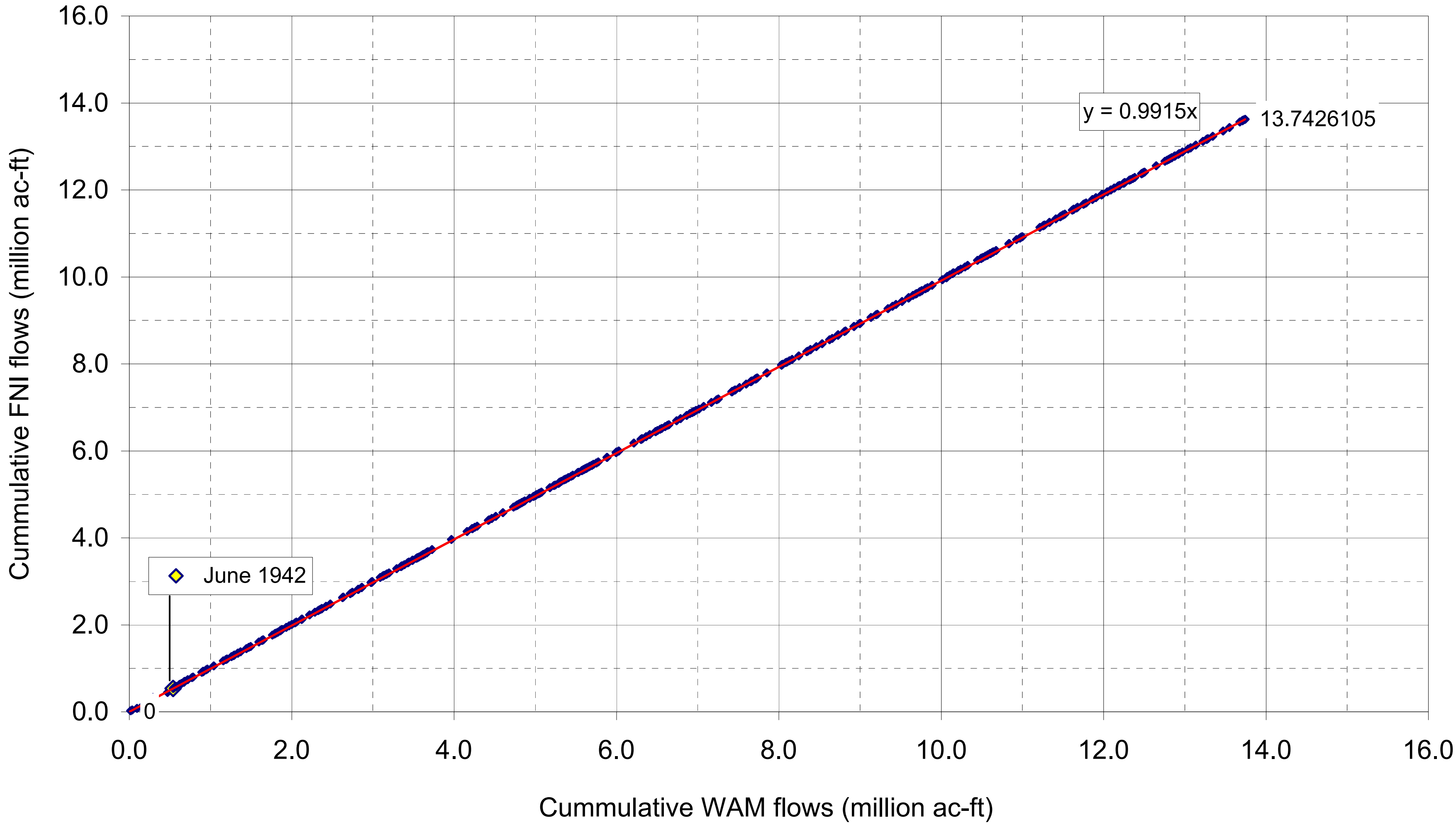


Figure C-5.1
Unappropiated WAM flows (Run 3) and SUPER Model flows (1941-1968)
Lake Chapman

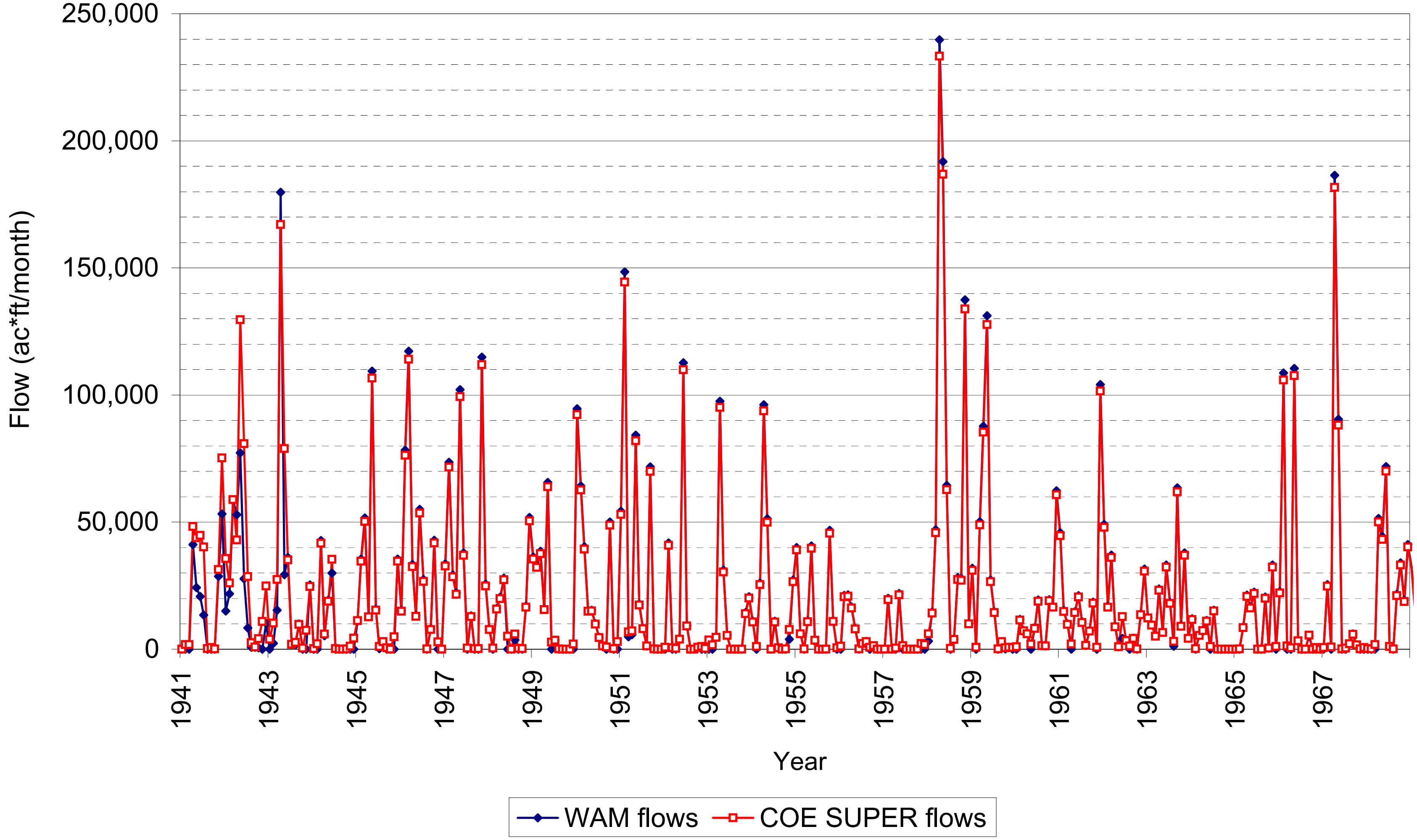


Figure C-5.2
Unappropiated WAM flows (Run 3) and SUPER Model flows (1969-1996)
Lake Chapman

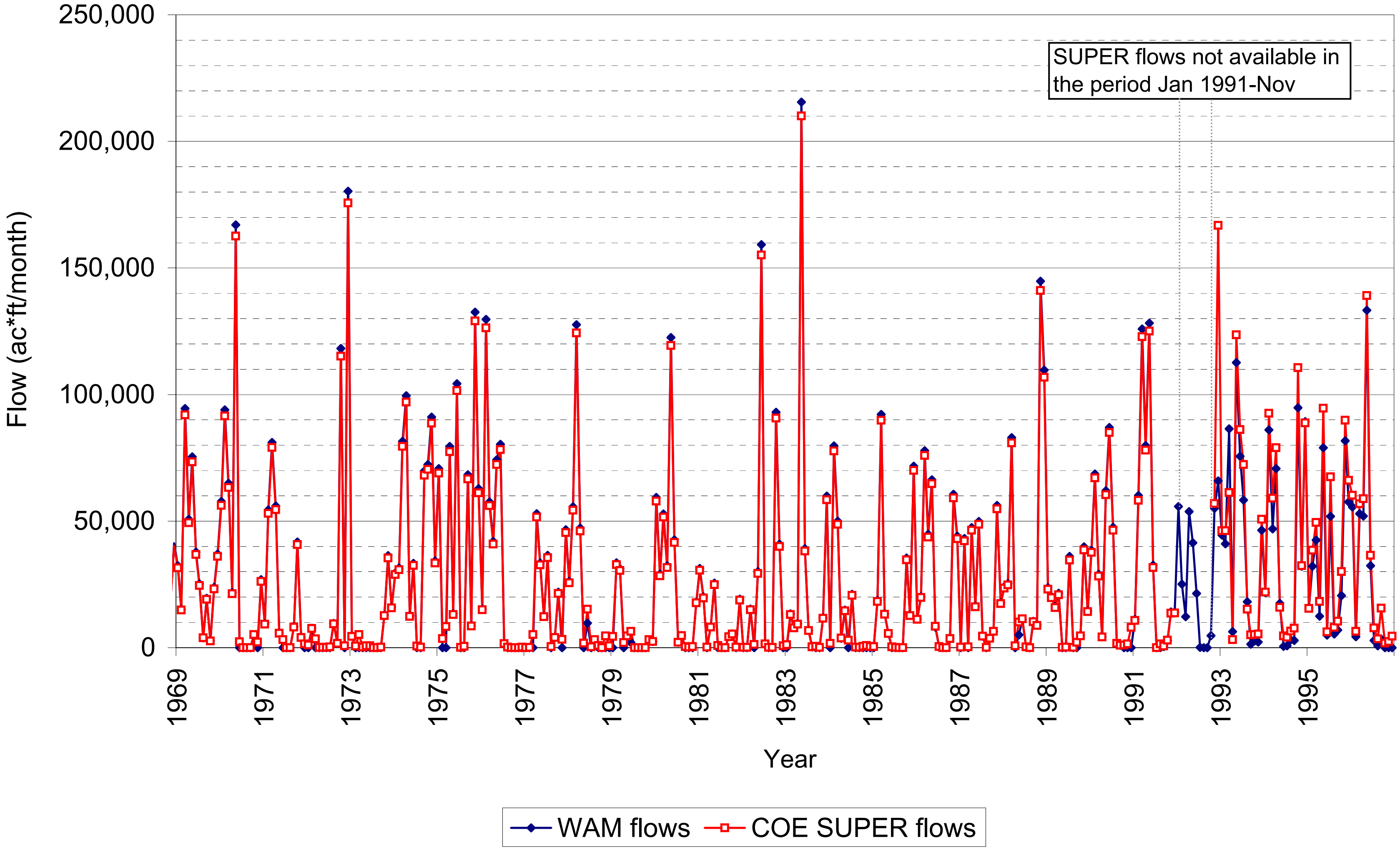


Figure C-6
Difference unappropiated WAM flows (Run 3) and COE SUPER Model flows
Lake Chapman

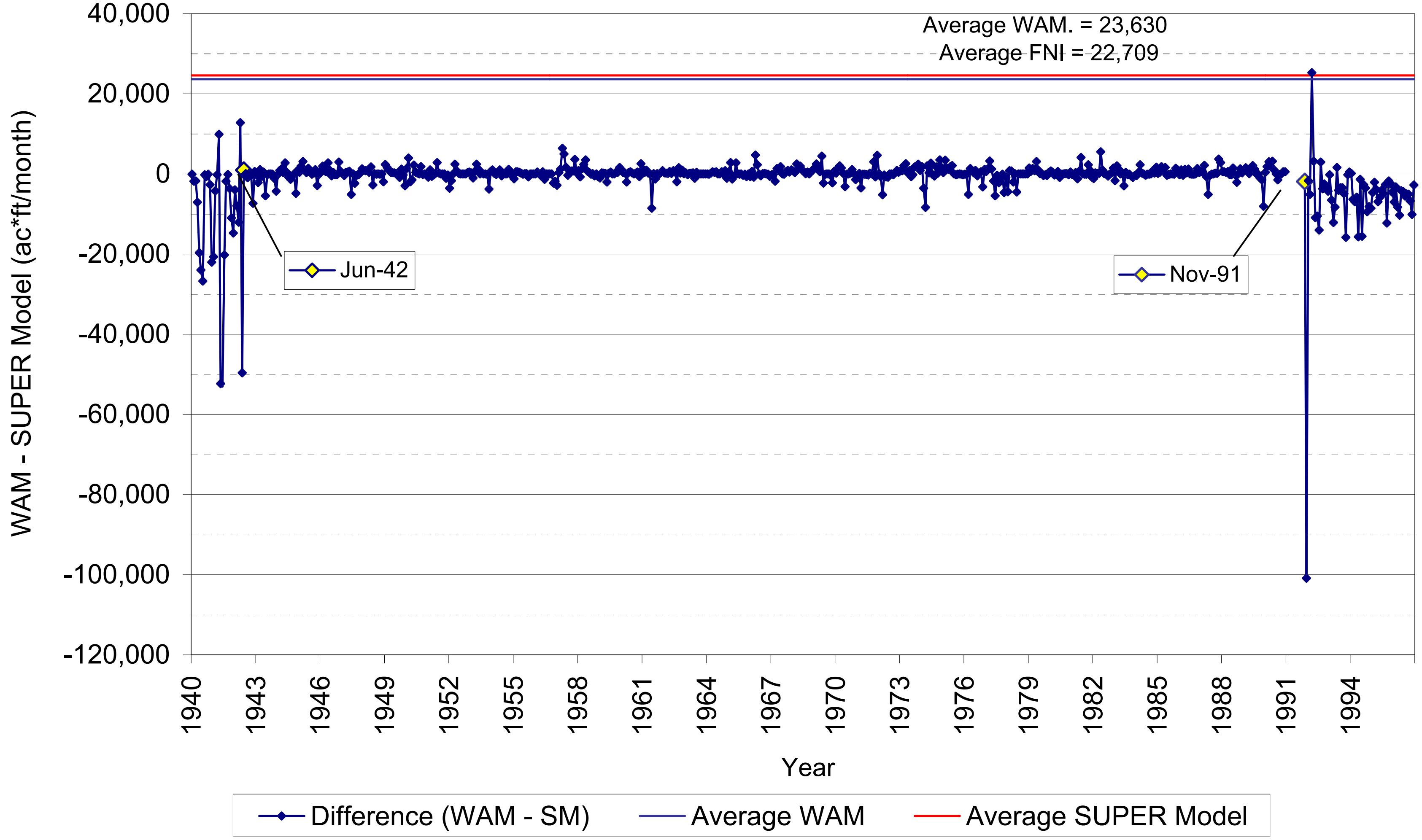


Figure C-7.1
Unappropiated WAM flows (Run 3) and COE Supermodel flows (Jun 1942-Dec 1996)
Lake Chapman

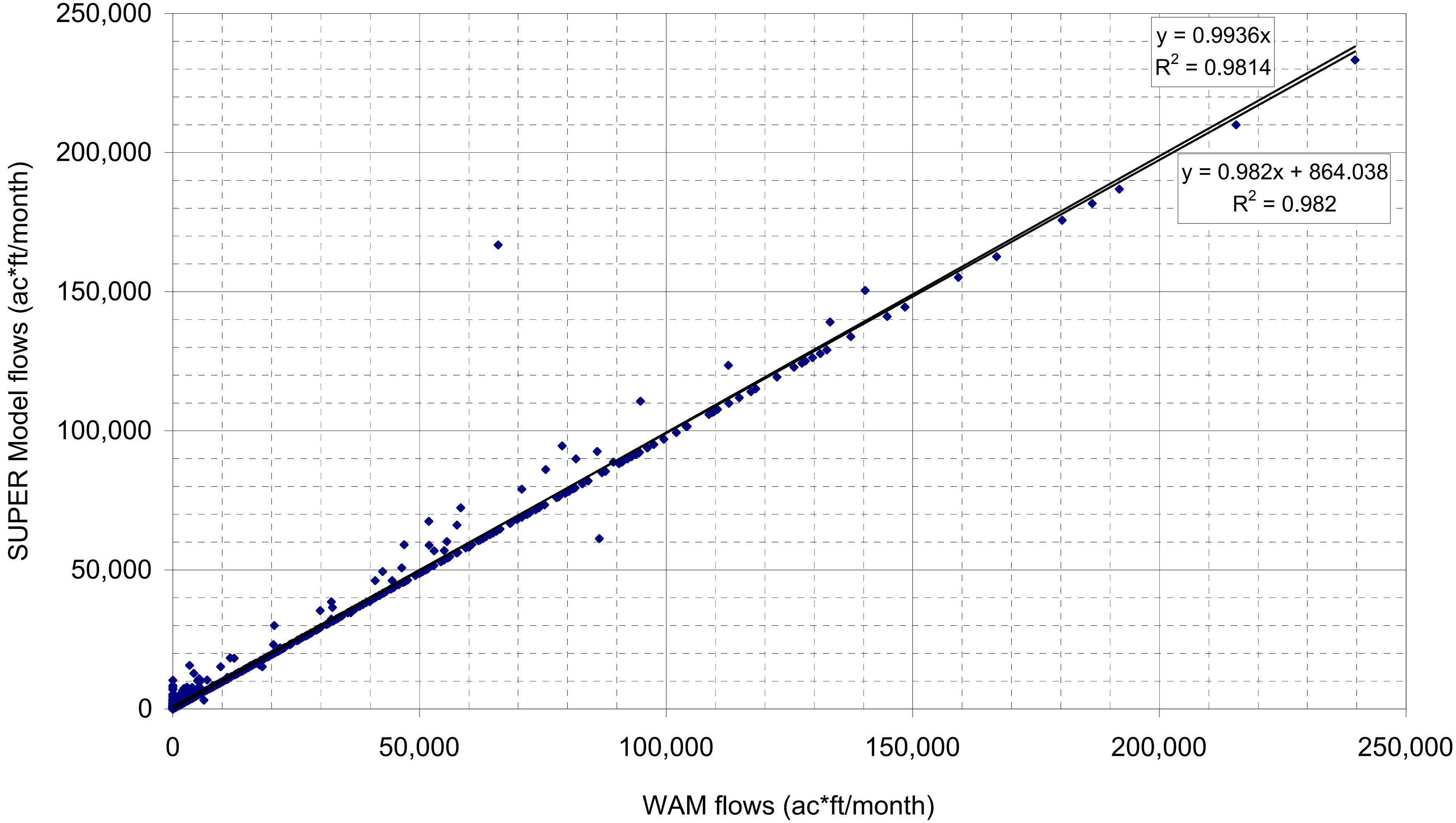


Figure C-7.2
Unappropiated WAM flows (Run 3) and COE SUPER Model flows (Full overlap 1940-1996)
Lake Chapman

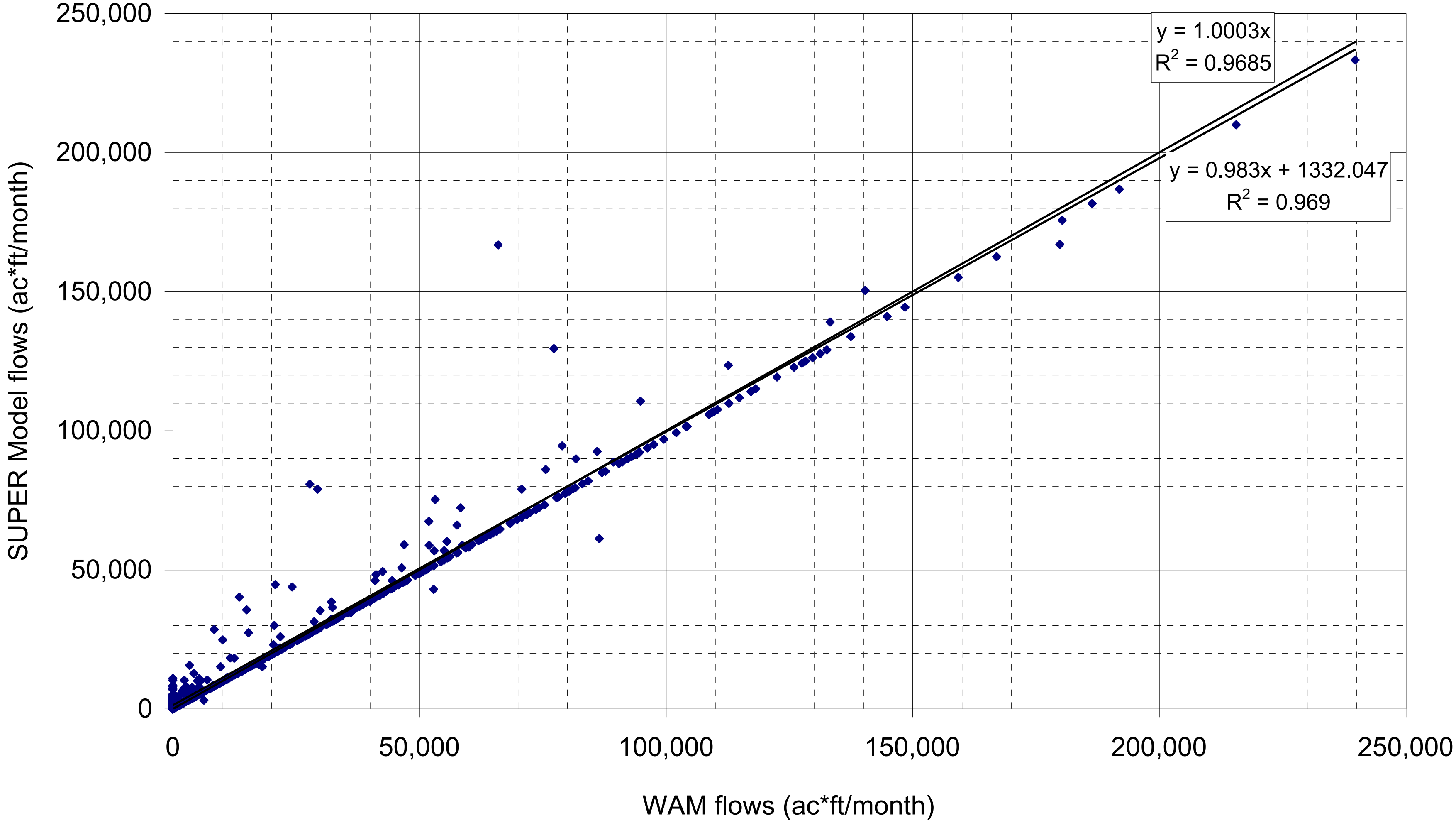


Figure C-8

Double mass curve unappropiated WAM (Run 3) and COE SUPER Model flows (1940-1990)

Lake Chapman

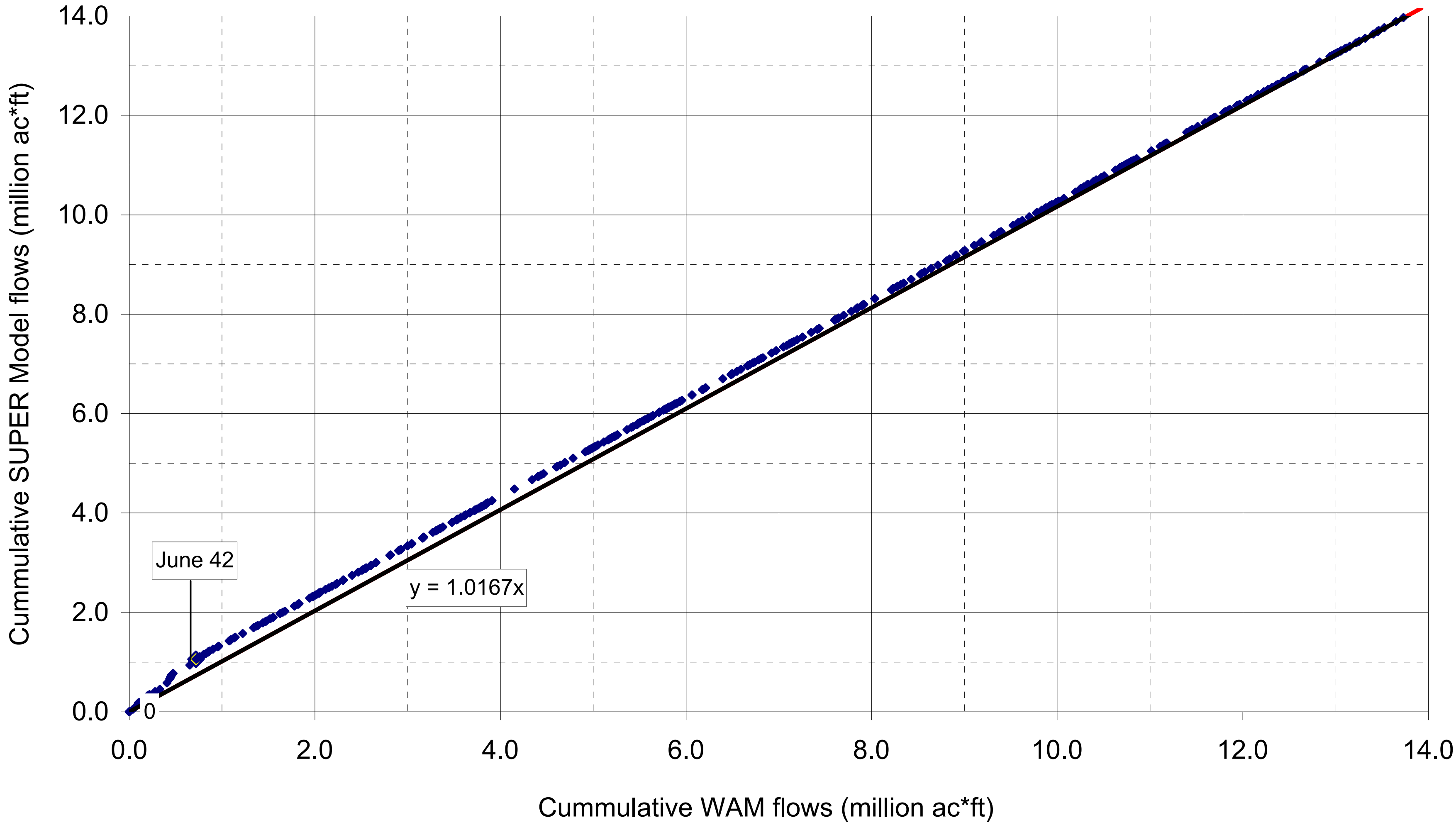


Figure C-9.1
COE SUPER Model flows and FNI flows (1941-1965)
Lake Chapman

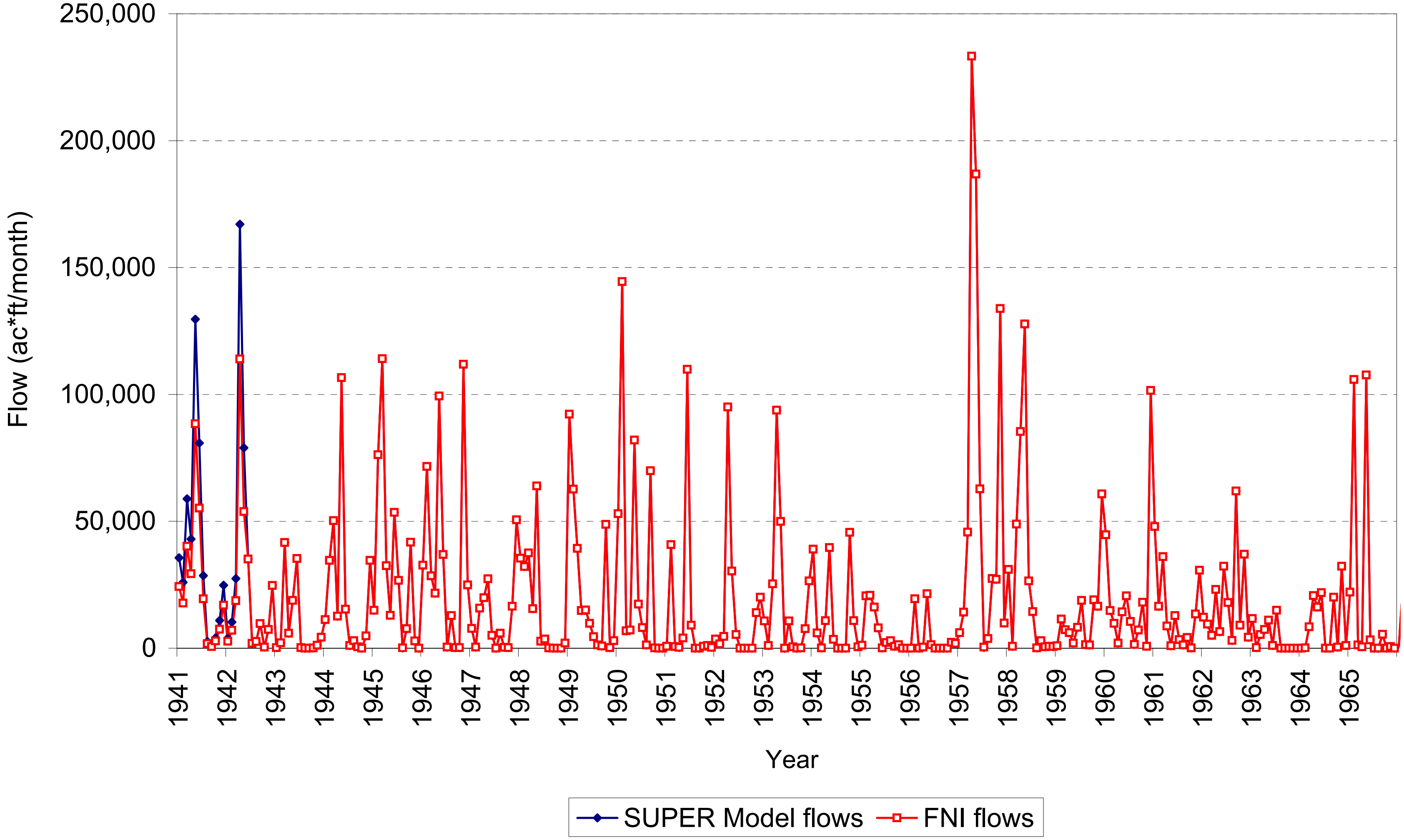


Figure C.9-2
COE SUPER Model flows and FNI flows (1966-1990)
Lake Chapman

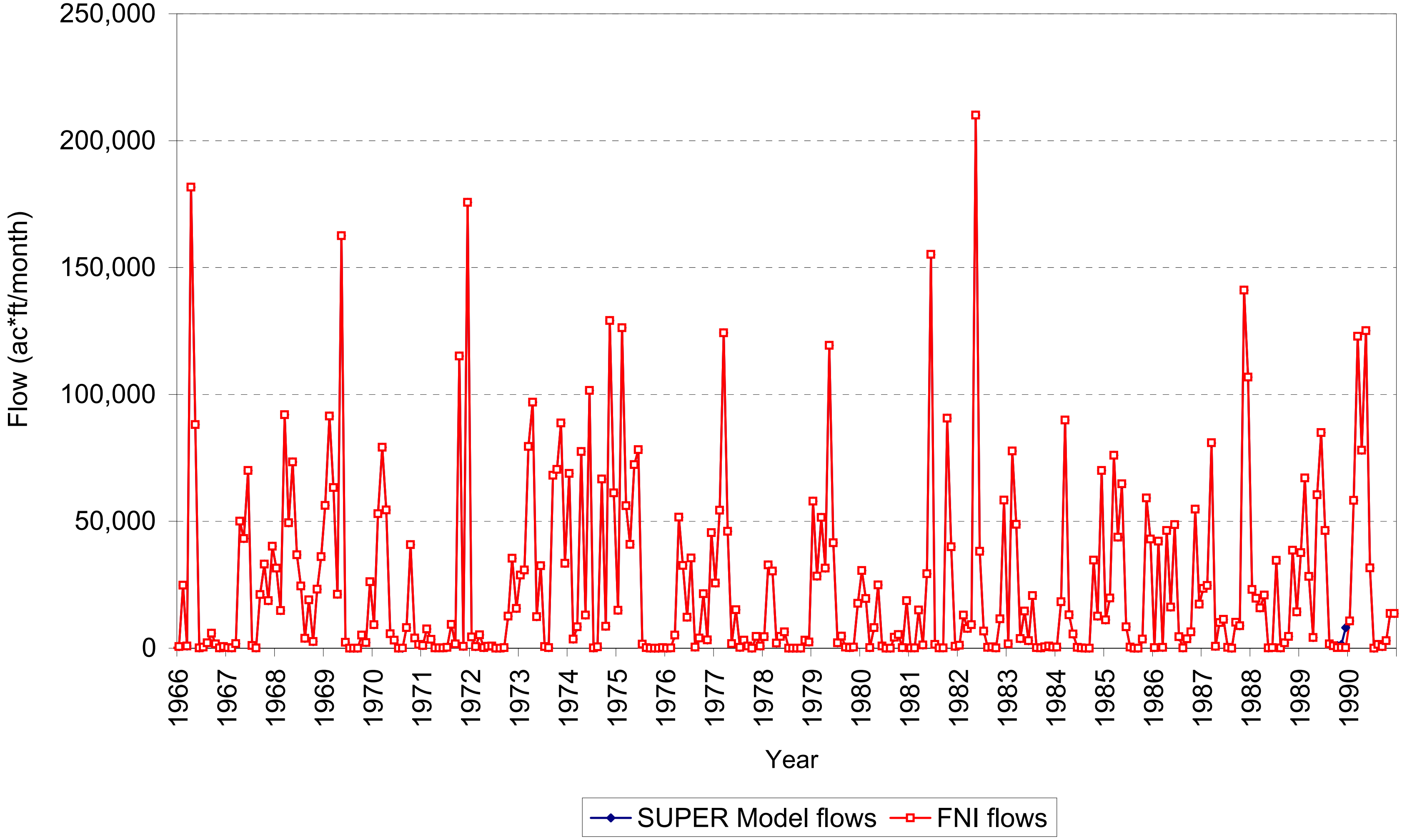


Figure C-10
COE SUPER Model flows and FNI flows
Lake Chapman

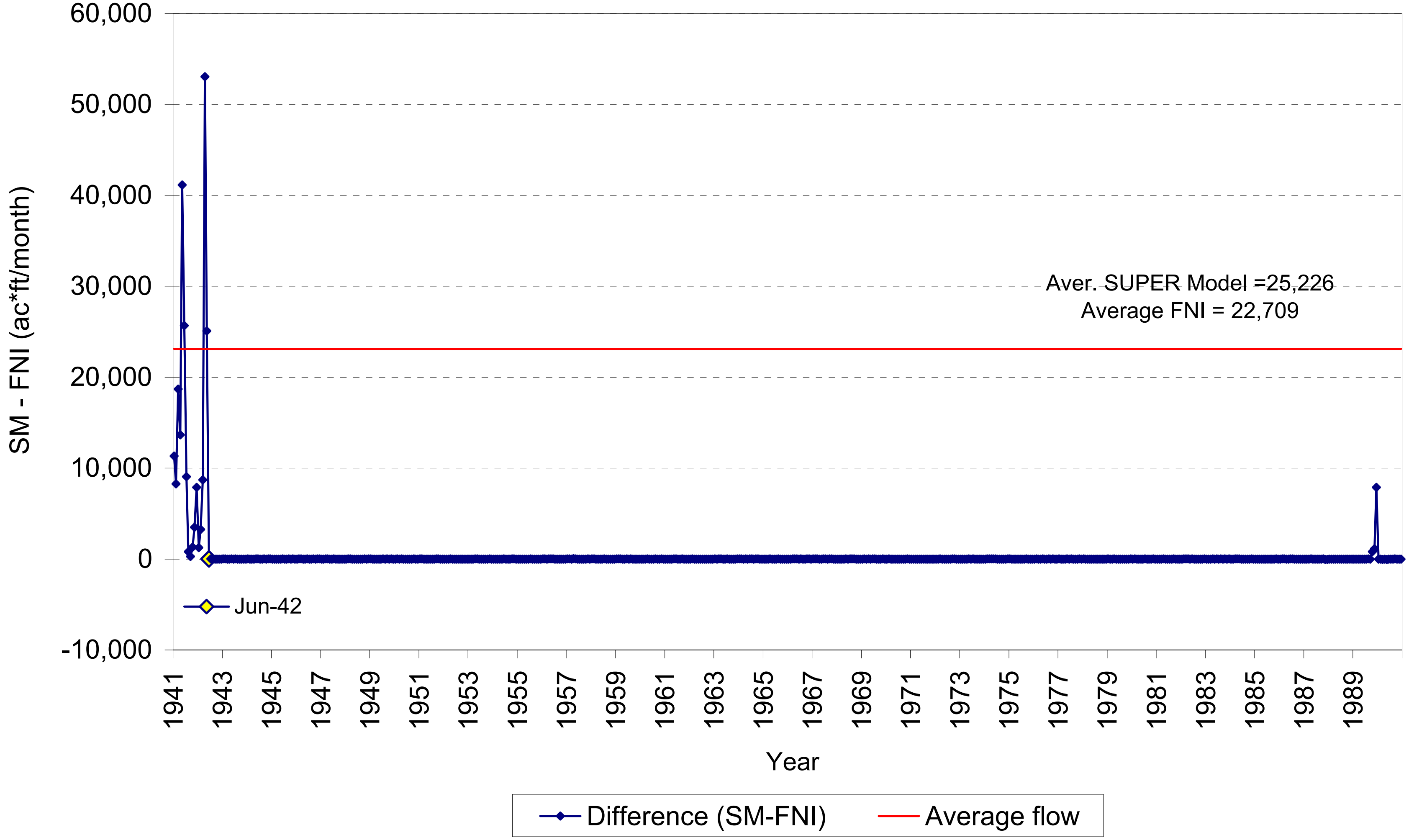


Figure C-11.1
SUPER Model flows (Run 3) and FNI flows (Jun 1942-Dec 1990)
Lake Chapman

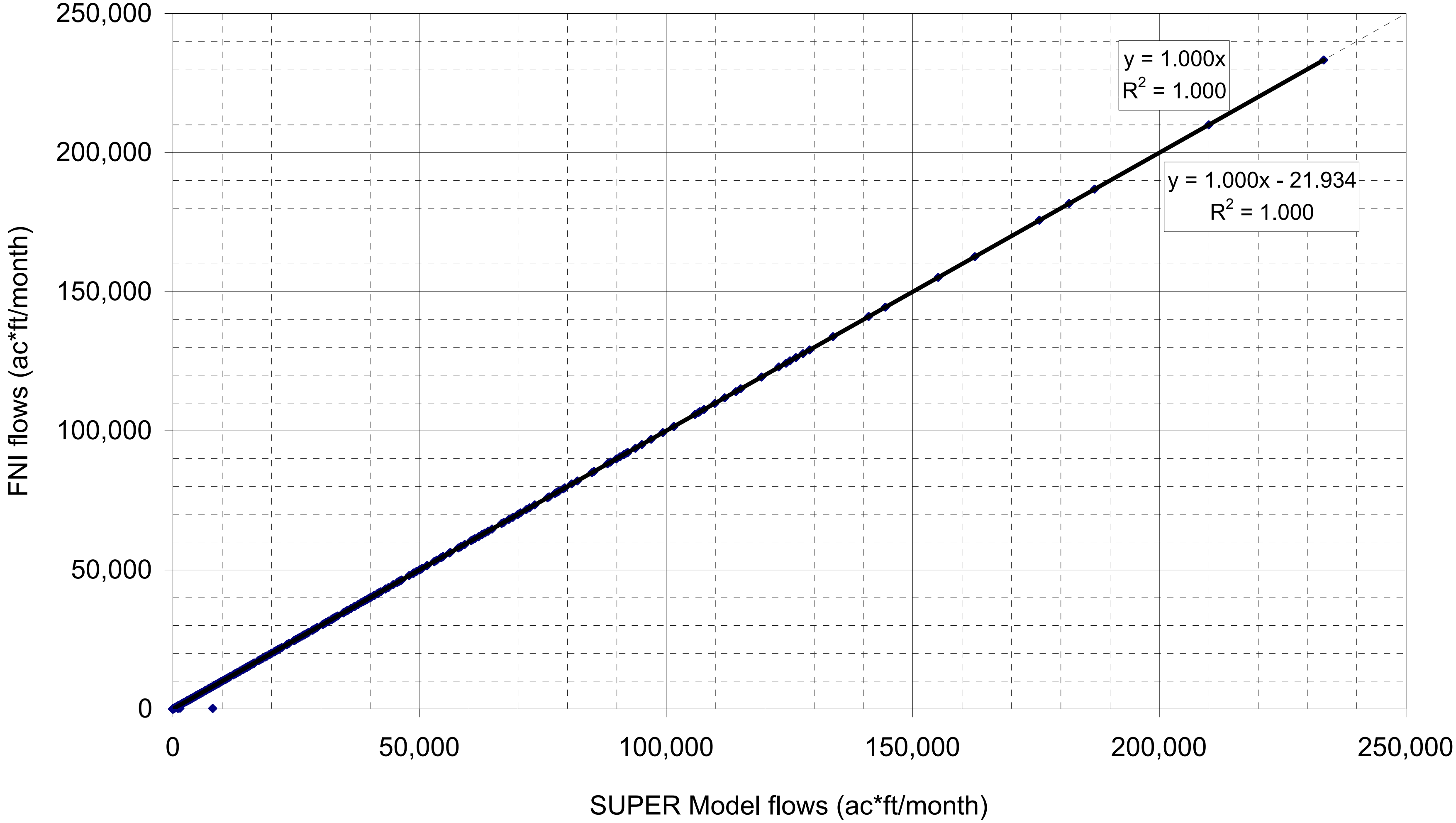


Figure C-11.2
SUPER Model flows (Run 3) and FNI flows (Full overlap period 1941-1990)
Lake Chapman

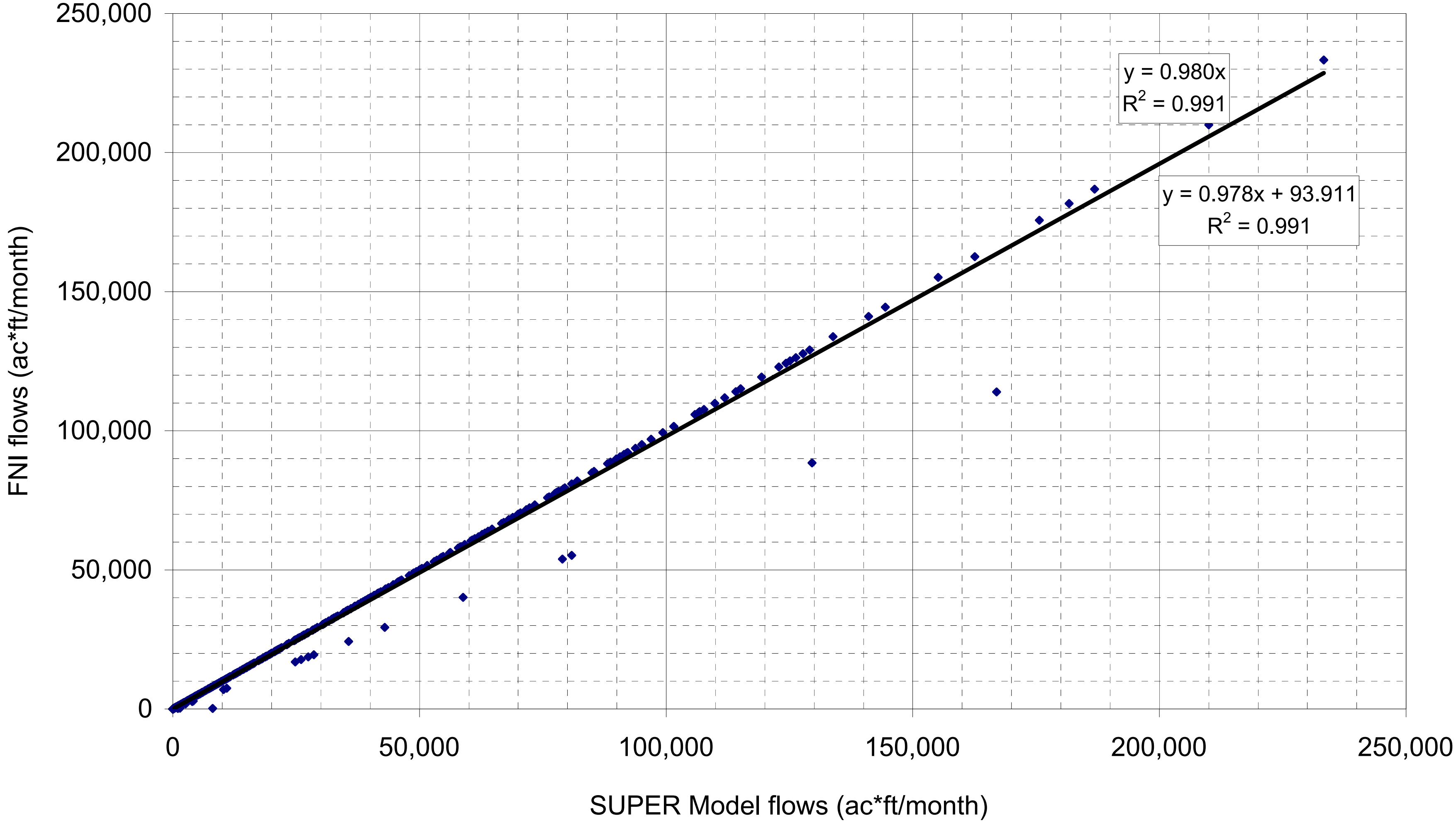
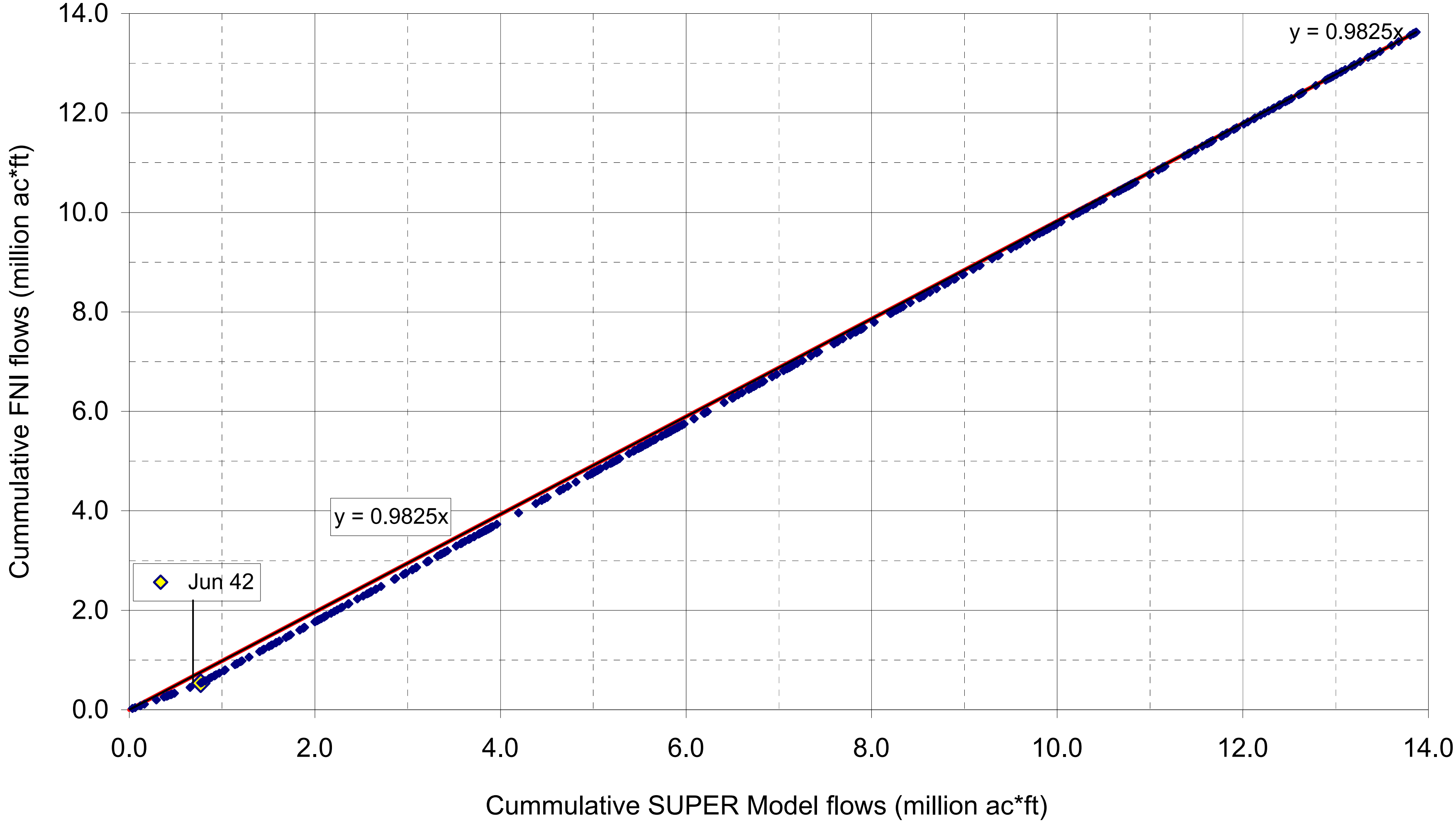


Figure C-12
Double mass curve COE SUPER Moldel flows and FNI flows
Lake Chapman



FNI flows are essentially the same as the SUPER model value for the period from June 1942 to December 1990. There is only one month (Dec 1989) in the 582-month period where the values do not match. WAM flows tend to be a bit higher than the other two series, especially in peak values. These small differences may be result of discrepancies in drainage areas. The WAM model relied on drainage areas that were calculated by the Center for Research in Water Resources (CRWR) using GIS methods, while the FNI flows used USGS drainage areas. It is likely that the Corps used USGS drainage areas as well. Table C-5 compares the drainage areas from the Sulphur WAM to USGS drainage areas.

Table C-5
Comparison of WAM and USGS Drainage Ares

WAM Control Point	**Gage Name**	**USGS Gage Number**	**WAM Drainage Area** (sq-miles)	**USGS Drainage Area** (sq-miles)
A10	South Sulphur River near Cooper	7342500	550	527
C10	Sulphur River near Talco	7343200	1380	1405
D10	White Oak Creek near Talco	7343500	522	494
E10	Sulphur River near Darden	7344000	2946	2774

Table C-6 summarizes the comparisons of the flows for Lake Jim Chapman. All three series in Lake Jim Chapman are consistent, and any of these series may be used for the current study.

Table C-6
Summary of Comparisons of Lake Jim Chapman Flows

Comparison (x vs. y)	Type	Equation	R^2	Overlap period	Figure
WAM VS FNI	Scatter	y = 0.968 x + 521.7	0.999	6/42-12/90	C-3.1
	Scatter	y = 0.955 x + 845.1	0.990	1/41-12/90	C-3.2
	Scatter	y = 0.9748 x	0.999	6/42-12/90	C-3.1
	Scatter	y = 0.9653 x	0.990	1/41-12/90	C-3.2
	Double mass	y = 0.9915 x	-	1/41-12/90	C-4
WAM VS SUPER	Scatter	y = 0.982 x + 864	0.982	6/42-12/90 and 11/91-12/96	C-7.1
	Scatter	y = 0.983 x + 1332	0.969	1/40-12/90 and 11/91-12/96	C-7.2
	Scatter	y = 0.9936 x	0.981	6/42-12/90 and 11/91-12/96	C-7.1
	Scatter	y = 1.0003 x	0.969	1/40-12/90 and 11/91-12/96	C-7.2
	Double mass	y = 1.0167 x	-	1/41-12/90	C-8
SUPER VS FNI	Scatter	y = x - 21.93	1.000	6/42-12/90	C-11.1
	Scatter	y = 0.978 x + 93.91	0.991	1/41-12/90	C-11.2
	Scatter	y = x	1.000	6/42-12/90	C-11.1
	Scatter	y = 0.98 x	0.991	1/41-12/90	C-11.2
	Double mass	y = 0.9825 x	-	1/41-12/90	12

Comparison for Lake Wright Patman

Comparisons of flow for Lake Wright Patman are presented in Figures C-13 through C-24. These comparisons are for the total flow into Lake Wright Patman below Lake Jim Chapman. All flows have been adjusted to remove historical spills or releases from Lake Jim Chapman.

As shown in Figures C-13 and C-14, the WAM and FNI flows are not as consistent on a month-by-month basis as the Lake Jim Chapman flows. The WAM flows tend to be higher than the FNI flows as well. However, as shown in Figures 15 and 16, when looked at on a long-term basis the flows are consistent over time. The double mass curve in Figure C-16 shows a distinct break some time in 1967. The cause of this break is unknown.

The COE flows and WAM flows are also inconsistent on a month-by-month basis, which is probably a result of different methodology used to calculate the flows. WAM flows tend to be greater than the SUPER model flows. However, a positive difference (WAM minus SUPER model) in one month is often compensated by a negative difference in the consecutive period (see Figure C-18). On a long-term basis, the flows compare well, as shown in Figures C-19 and C-20. There are some small breaks in the double mass curve, but they are much less pronounced than the comparison with FNI flows.

FNI and SUPER model series are consistent for the period January 1941 to December 1956. During this period, the gage in the Sulphur River near Darden (USGS 73440000) was in operation, and the values in both series are essentially equal (see Figure C-22). In January of 1957 this gage was discontinued, at which point the two flows appear to rely on different methods to calculate inflows. The FNI flows are based on the combined flow at the Sulphur River near Talco and White Oak Creek near Talco multiplied by the drainage area ratio of the reservoir to gages. The Corps flows are most likely based on a mass balance of Lake Wright Patman. The FNI flows tend to be slightly higher than the SUPER model flows. The double mass curve shows a change in the relationship of the two flows after Mar 1967 (see Figure C-24). The source of this discrepancy is not clear.

Table C-7 is a summary of the comparisons between flows for Lake Wright Patman. In general, the Lake Wright Patman inflows are not as consistent on a month-by-month basis as the inflows into Lake Chapman. However, all three sets of flows are fairly consistent on a long-term basis. The WAM and Corps flows have the most favorable comparison.

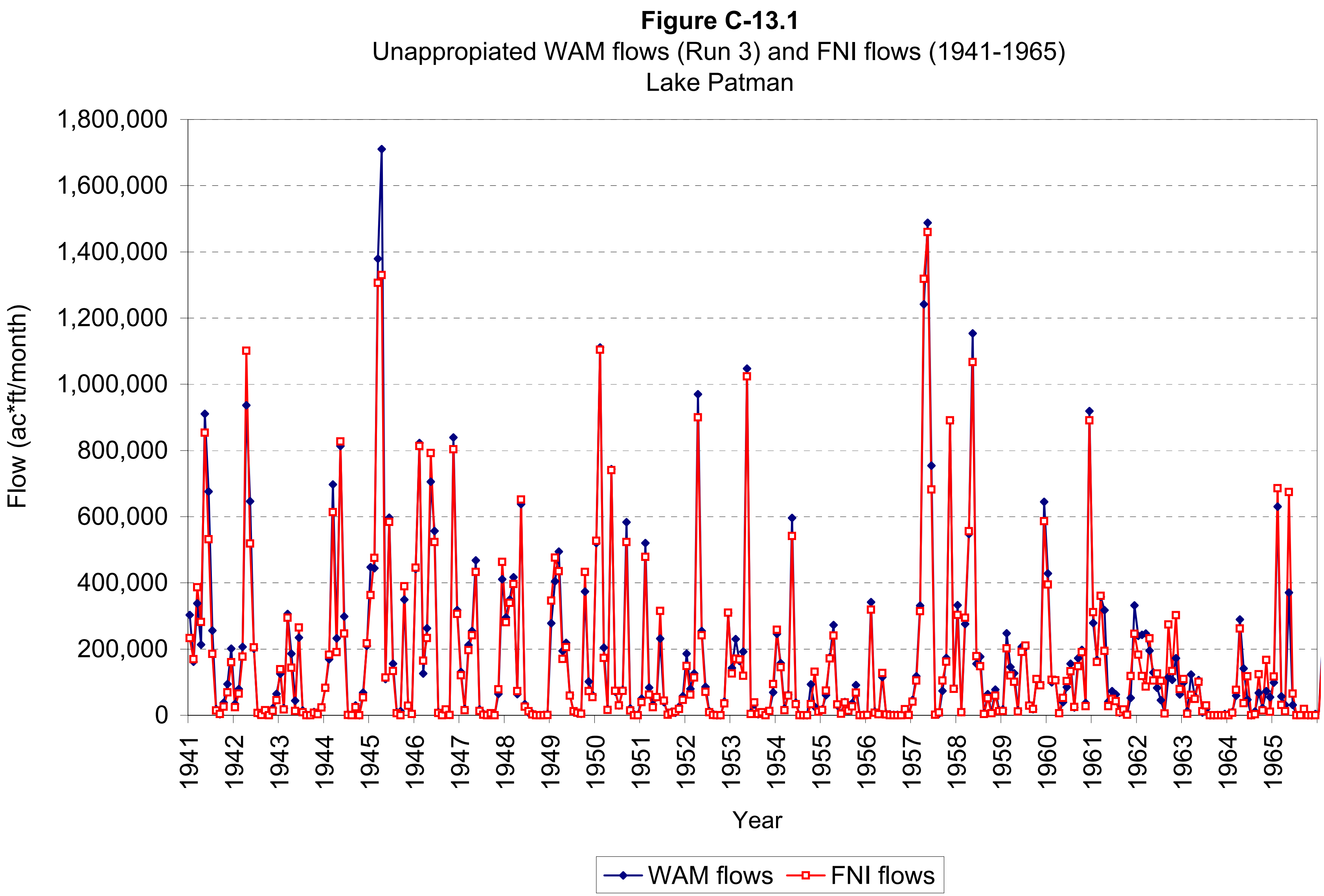


Figure C-13.1
Unappropiated WAM flows (Run 3) and FNI flows (1941-1965)
Lake Patman
Flow (ac*ft/month)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
Year
WAM flows
FNI flows

Figure C-13.2

Unappropiated WAM flows (Run 3) and FNI flows (1965-1986)

Lake Patman

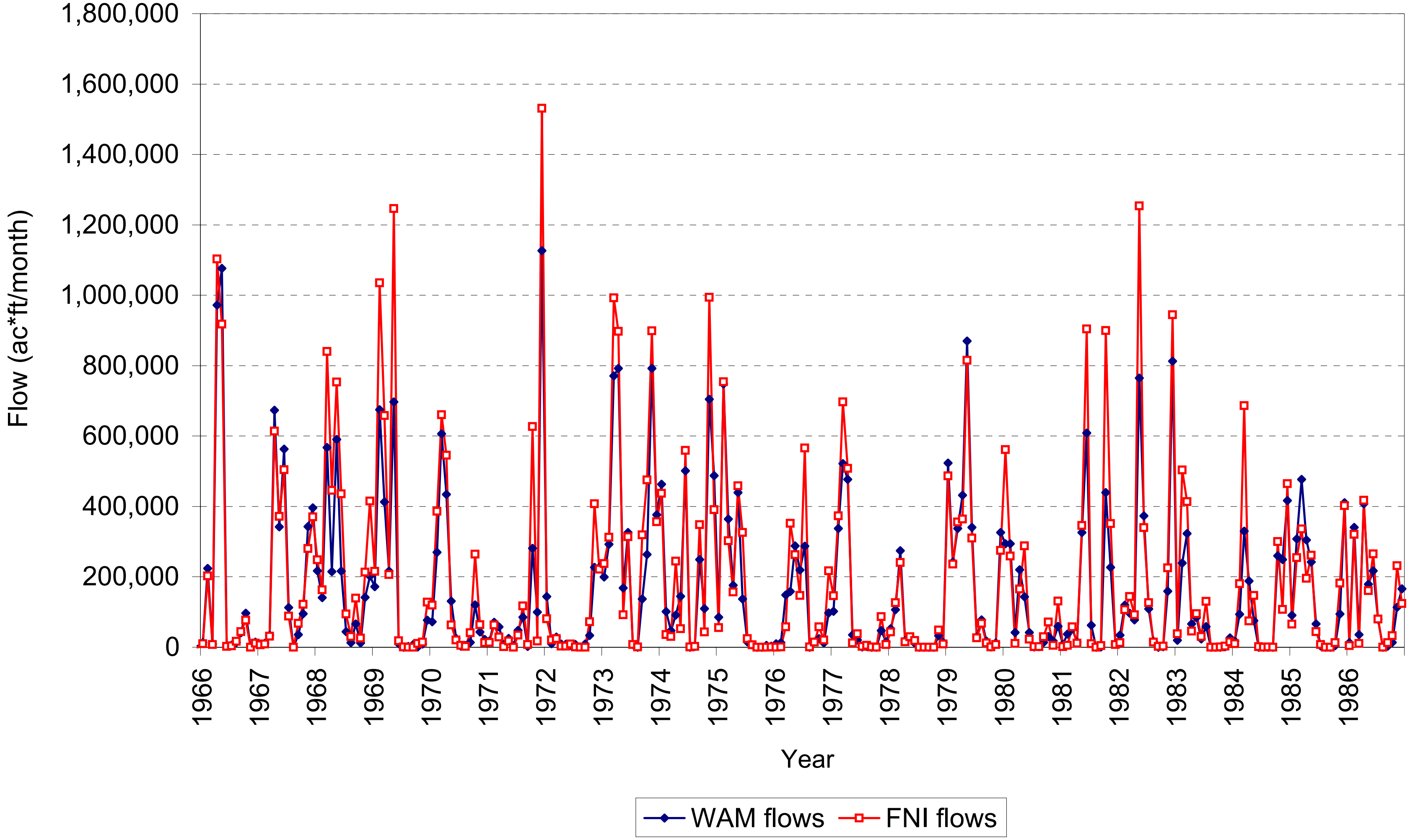


Figure C-14
Difference unappropiated WAM flows (Run 3) and FNI flows
Lake Patman

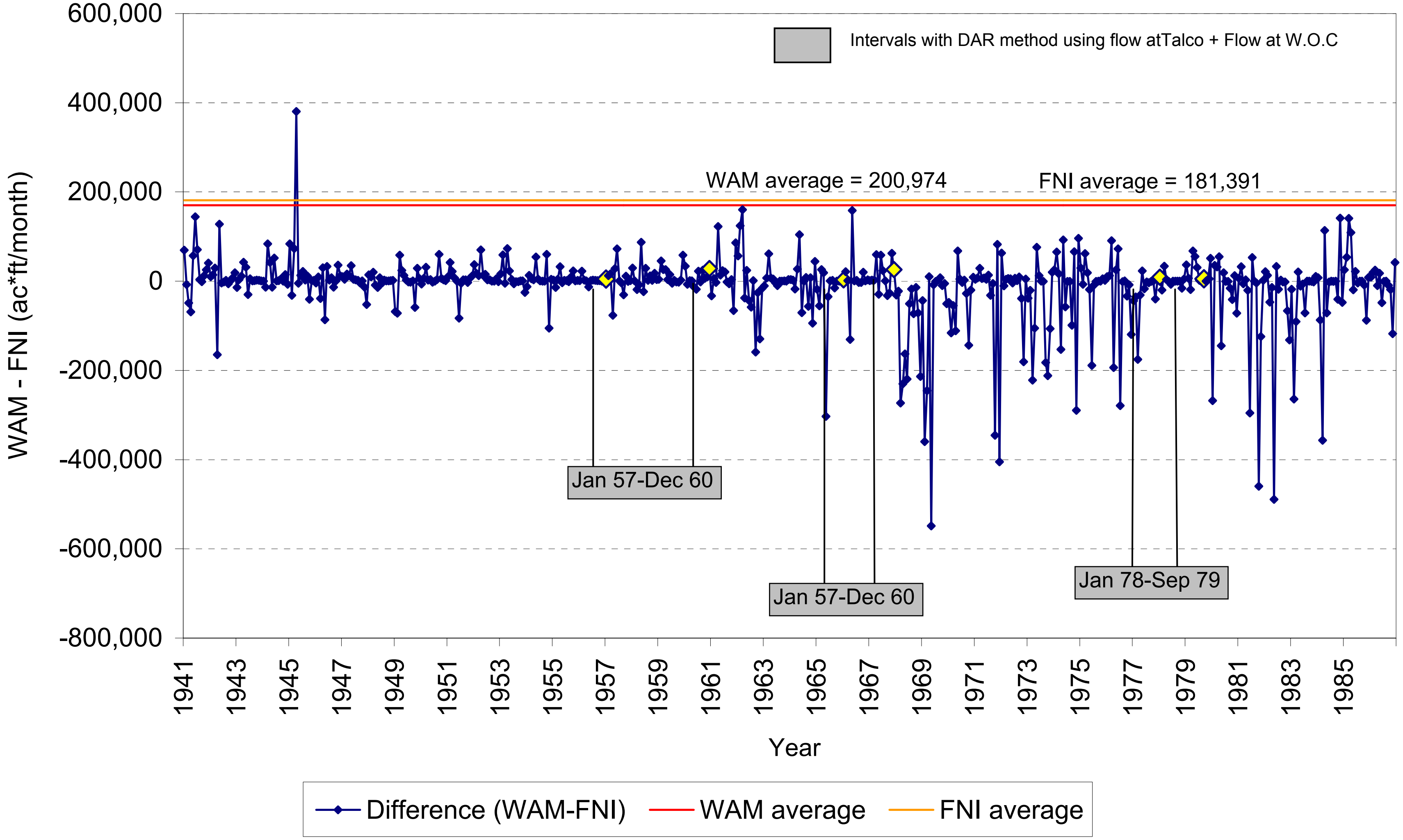


Figure C-15
Unappropiated WAM flows (Run 3) and FNI flows
Lake Patman

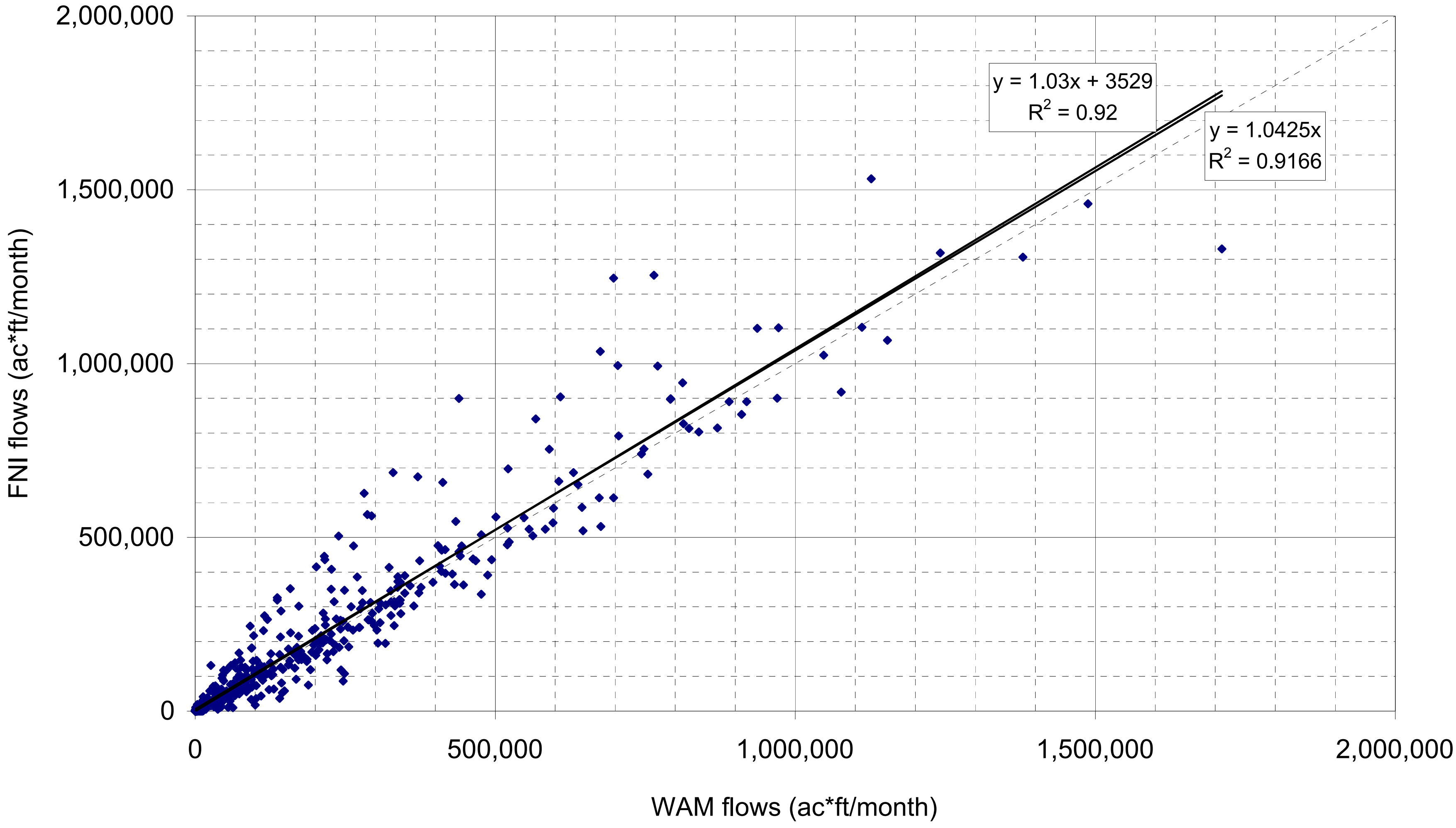


Figure C-16

Double mass curve unappropiated WAM flows (Run 3) and FNI flows

Lake Patman

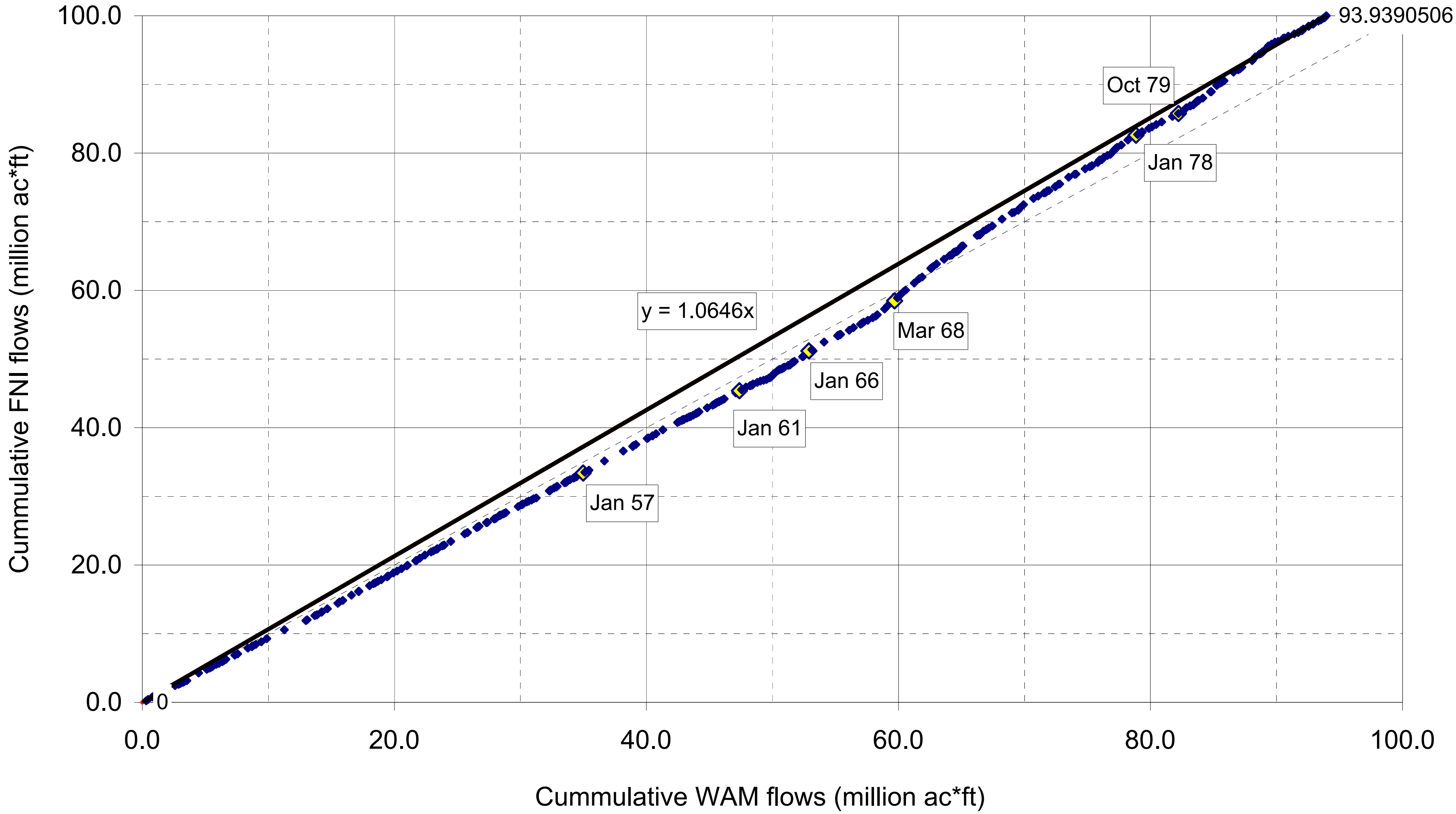


Figure C-17.1
WAM unappropiated flows (Run 3) and COE SUPER Model flows (1940-1968)
Lake Patman

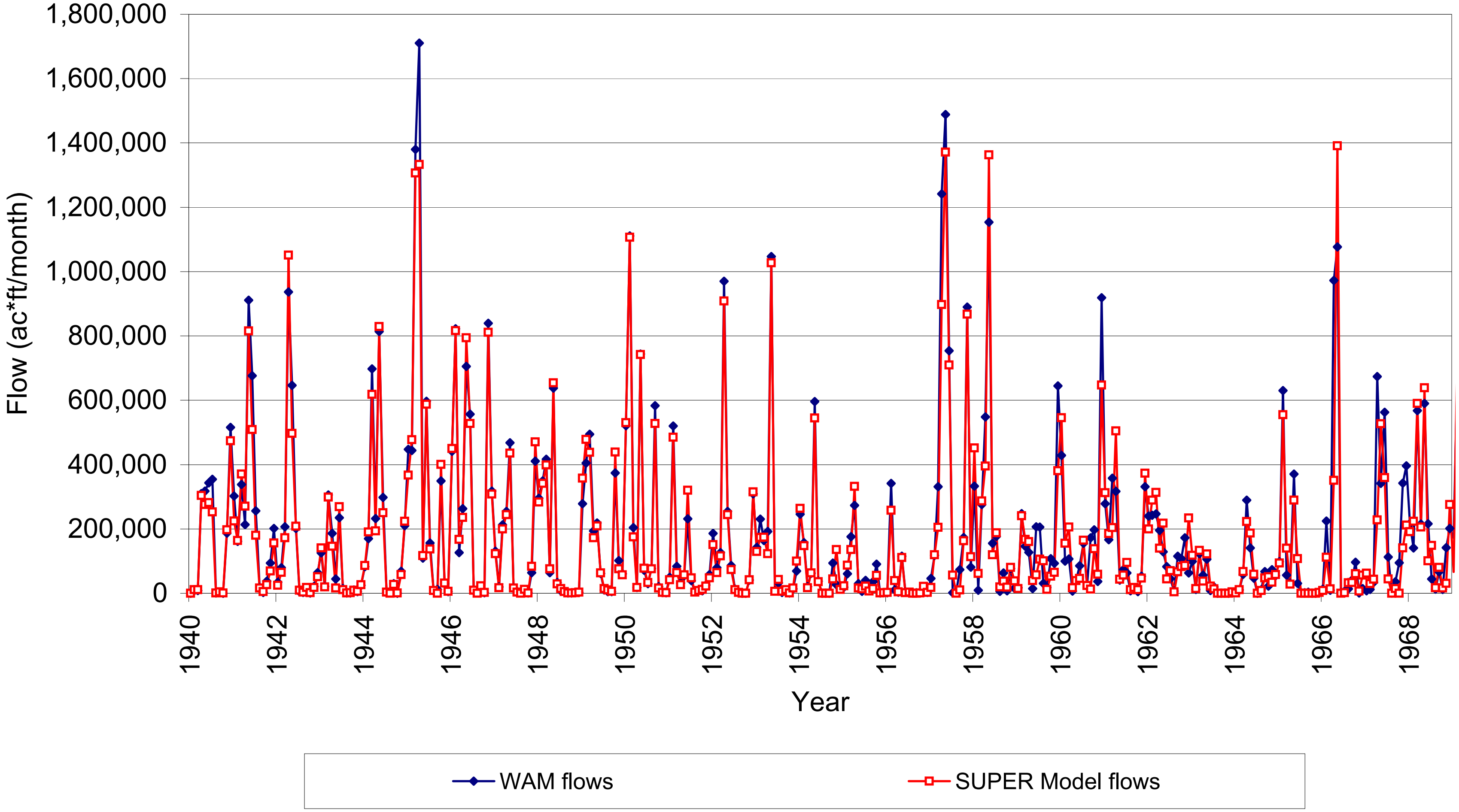


Figure C-17.2
WAM unappropiated flows (Run 3) and COE SUPER Model flows (1969-1996)
Lake Patman

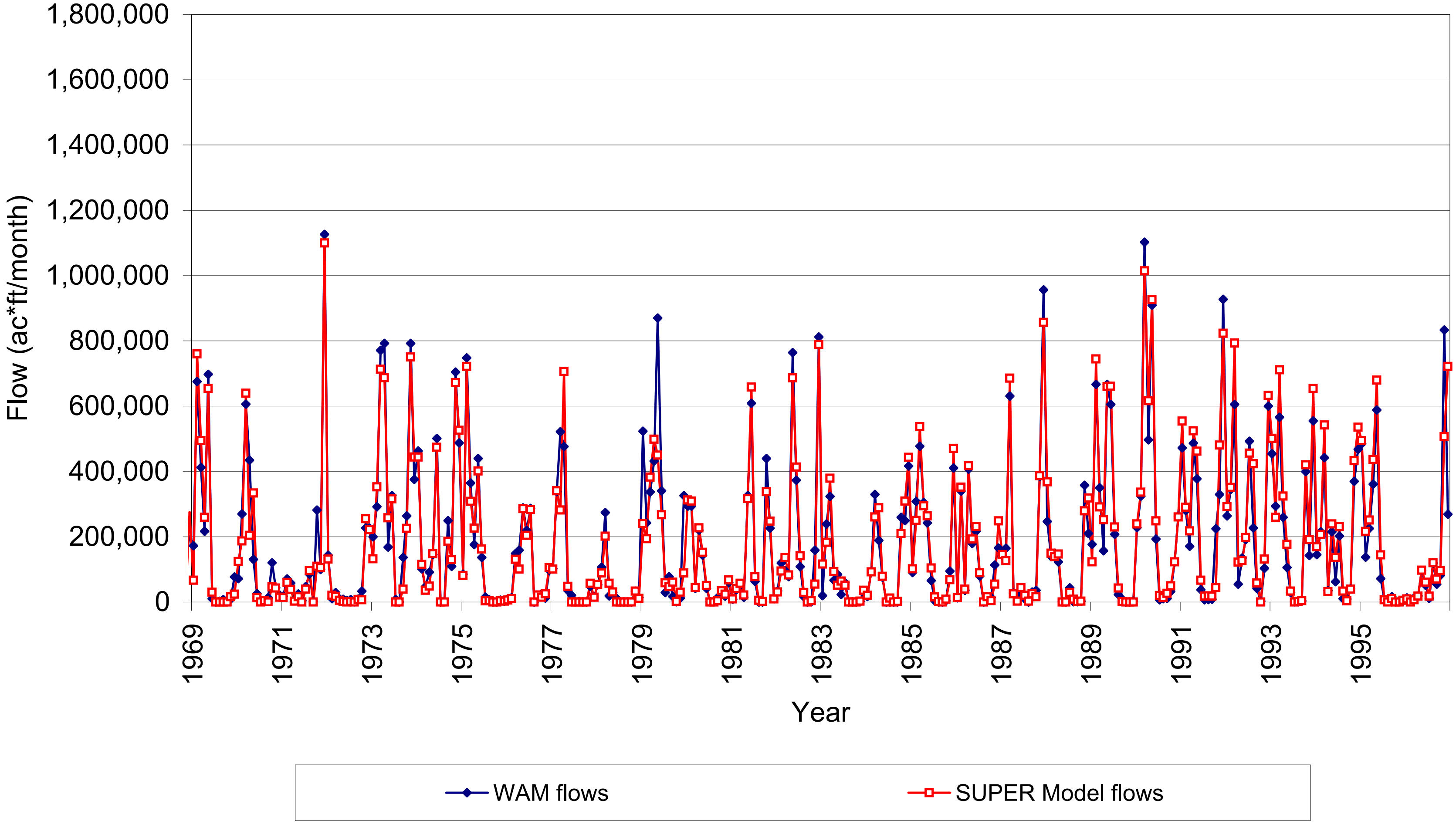


Figure C-18
WAM unappropiated flows (Run 3) and COE SUPER Model flows
Lake Patman

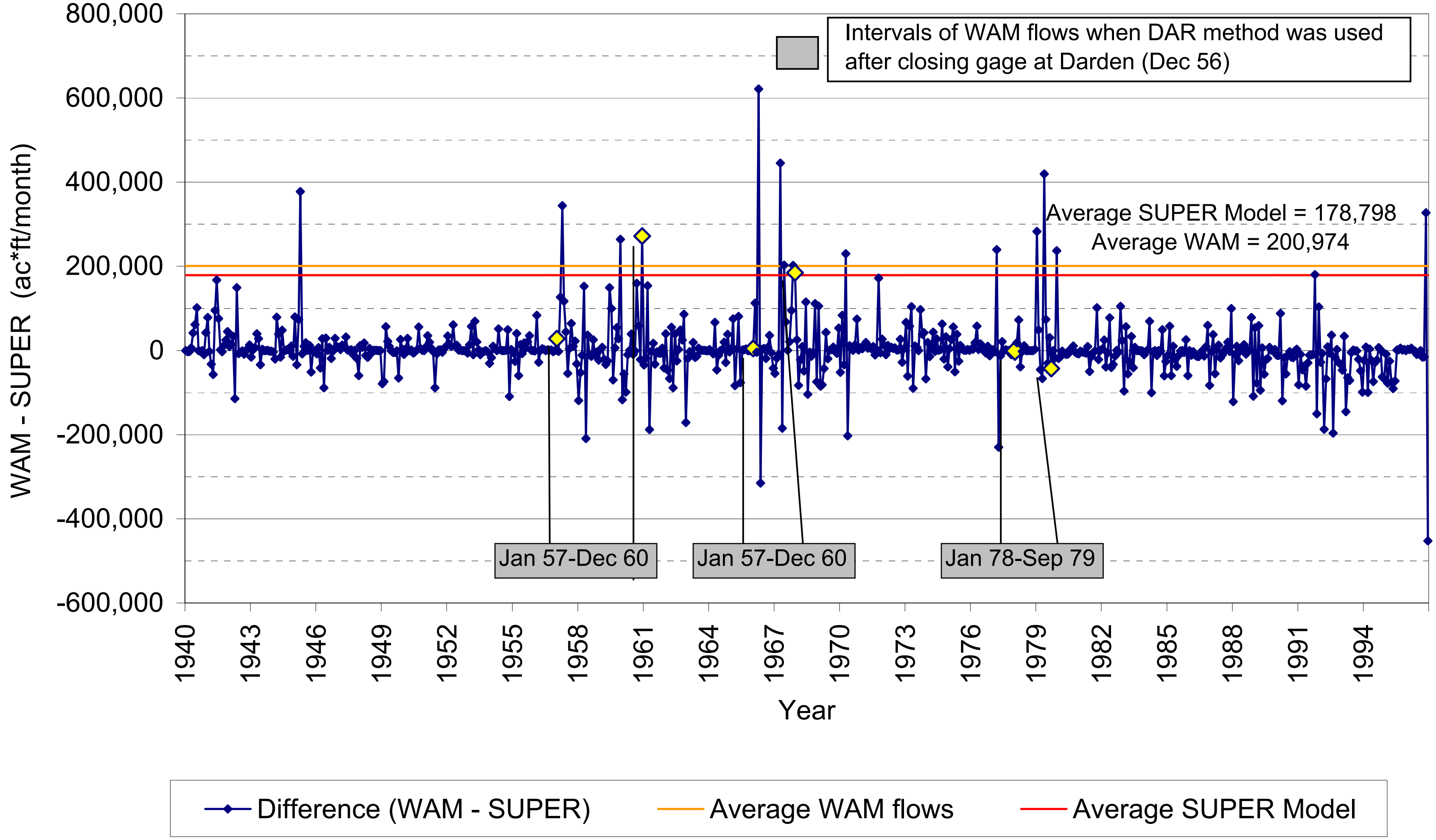


Figure C-19
WAM unappropiated flows (Run 3) and COE SUPER Model flows
Lake Patman

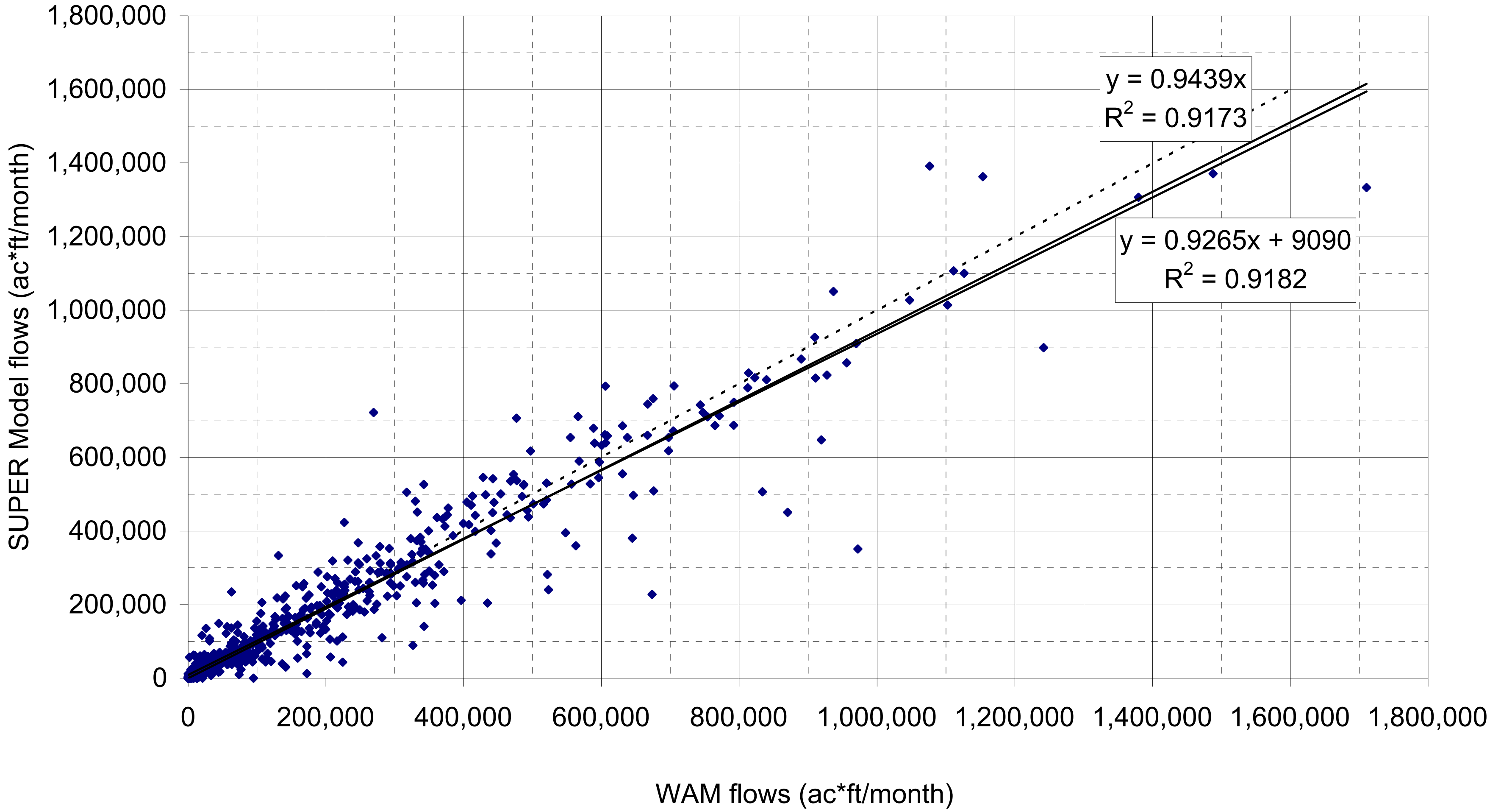
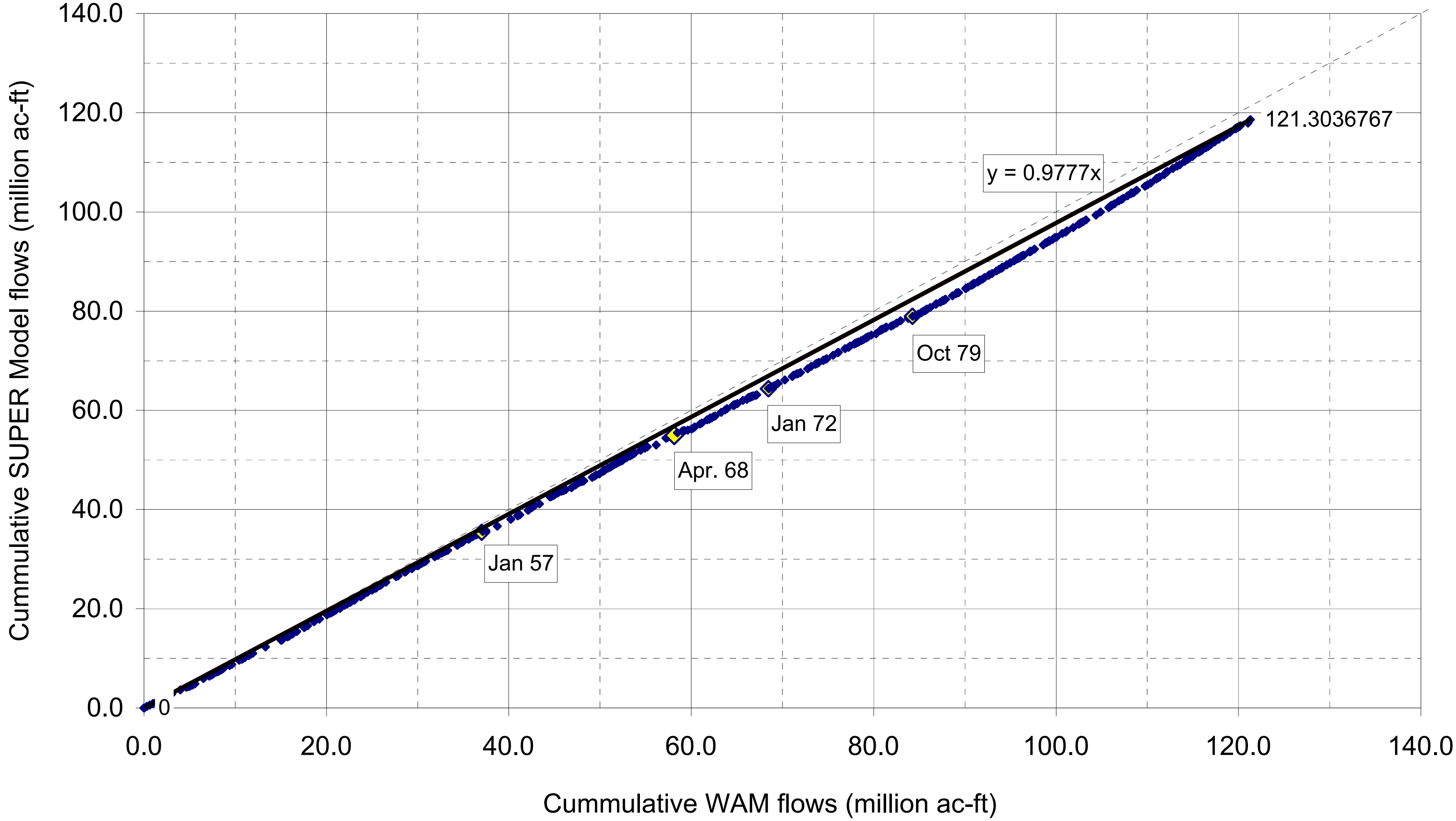


Figure C-20

Double mass curve unappropiated WAM flows (Run 3) and SUPER model flows

Lake Patman



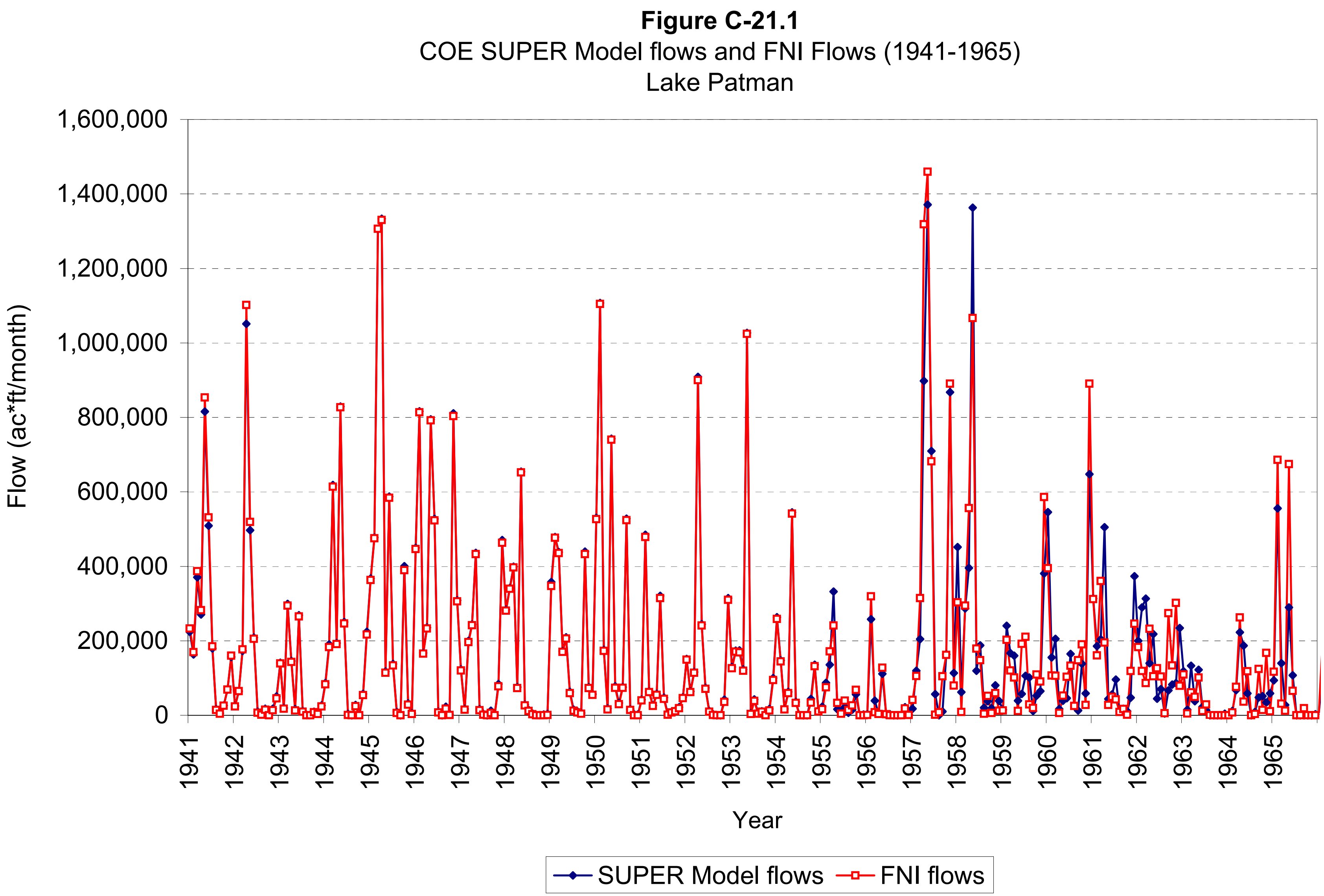
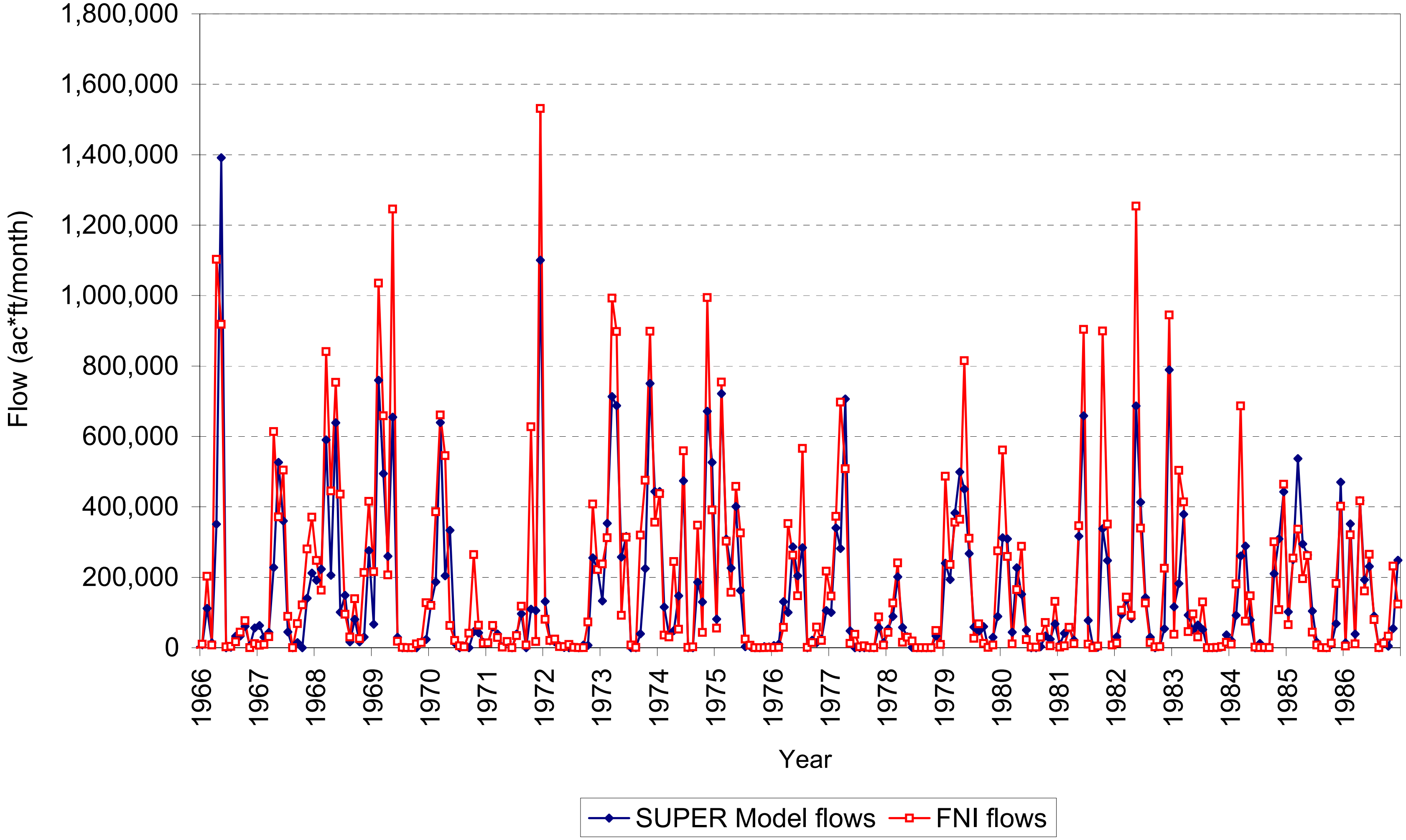


Figure C-21.1
COE SUPER Model flows and FNI Flows (1941-1965)
Lake Patman
Flow (ac*ft/month)
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
Year
SUPER Model flows
FNI flows

Figure C-21.2
COE SUPER Model flows and FNI Flows (1966-1986)
Lake Patman



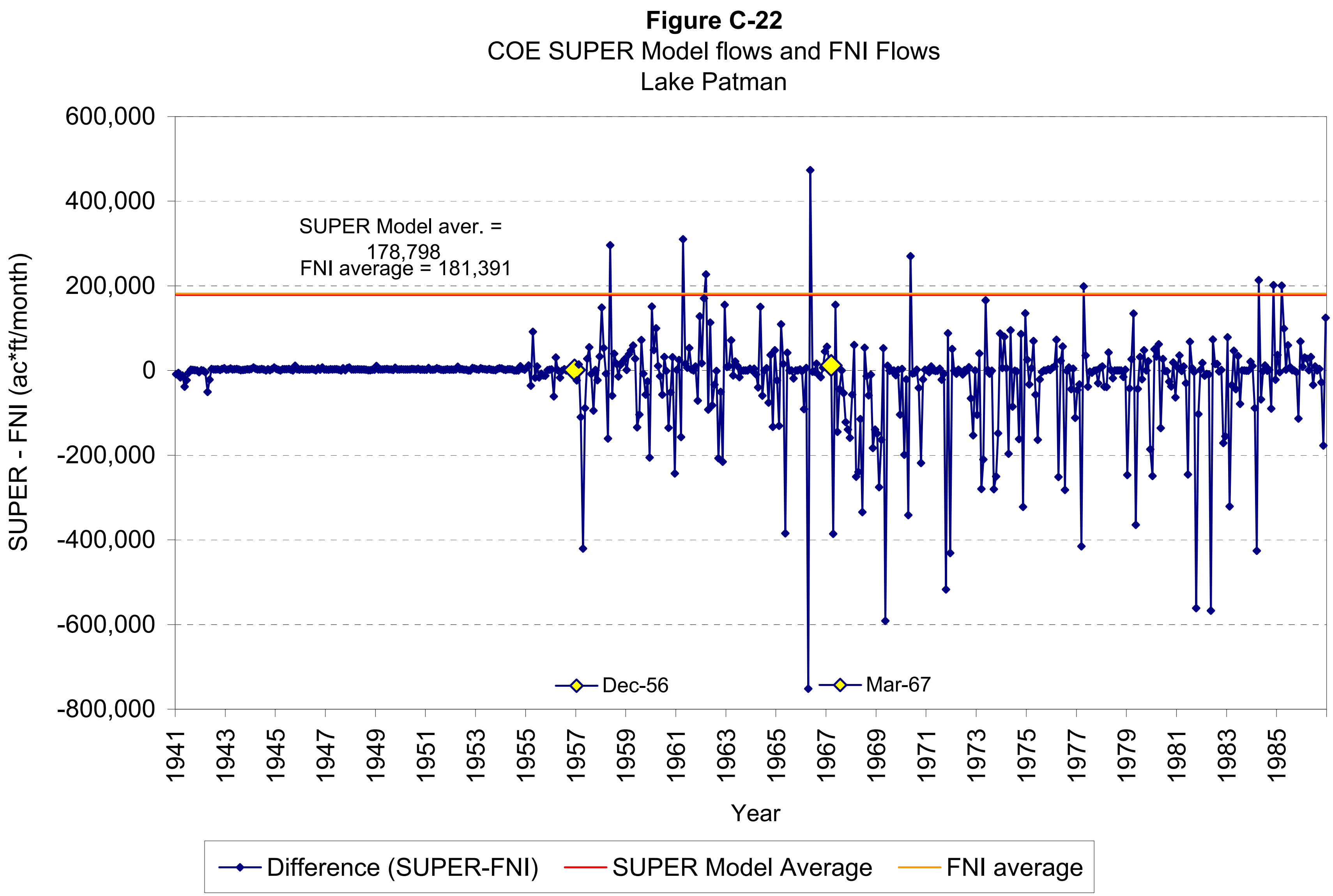


Figure C-22
COE SUPER Model flows and FNI Flows
Lake Patman
SUPER Model aver. = 178,798
FNI average = 181,391
SUPER - FNI (ac*ft/month)
600,000
400,000
200,000
0
-200,000
-400,000
-600,000
-800,000
Dec-56
Mar-67
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
Year
Difference (SUPER-FNI)
SUPER Model Average
FNI average

Figure C-23
COE SUPER Model flows and FNI flows
Lake Patman

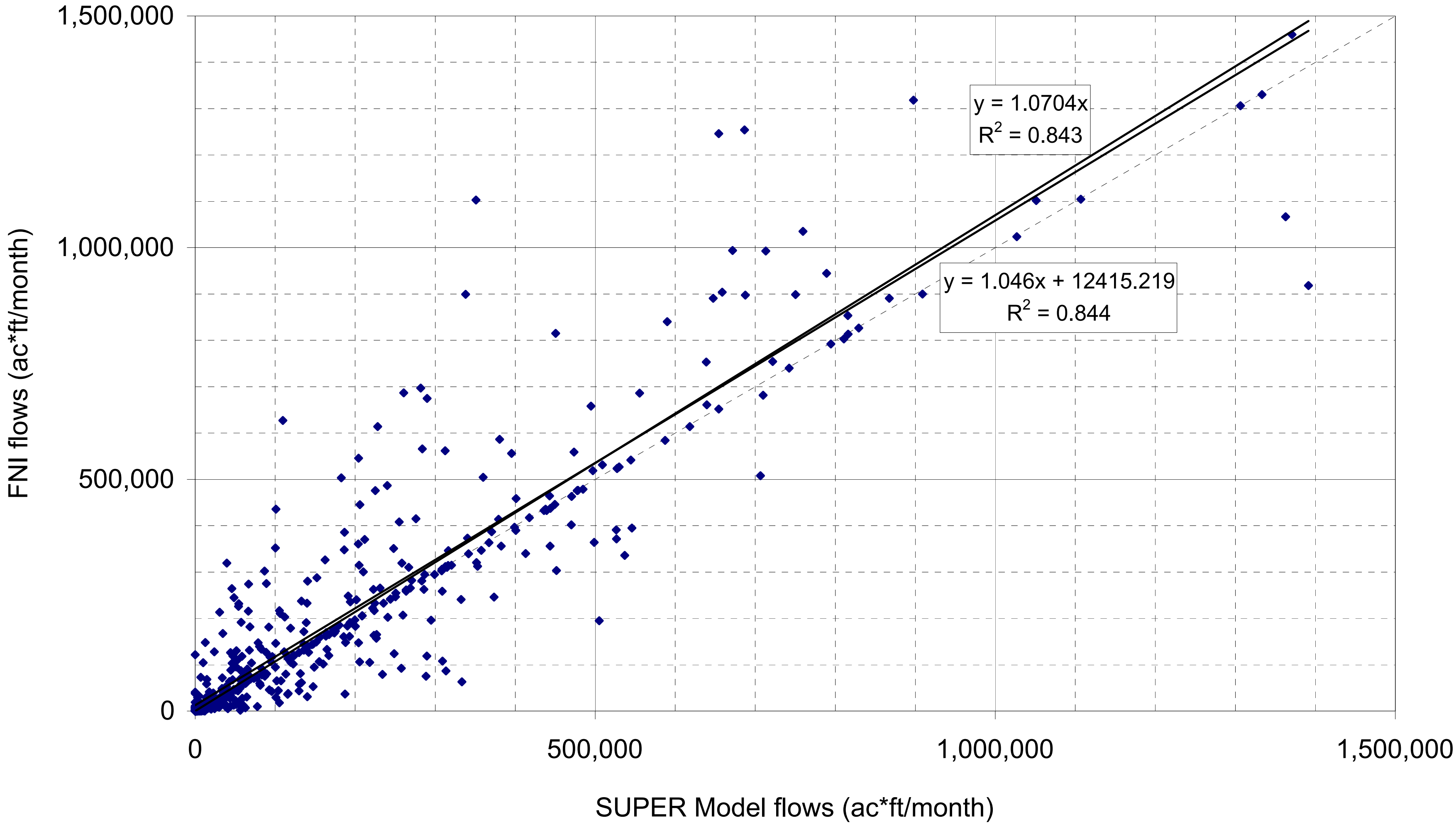


Figure C-24
Double mass curve COE Supermodel flows and FNI flows
Lake Patman

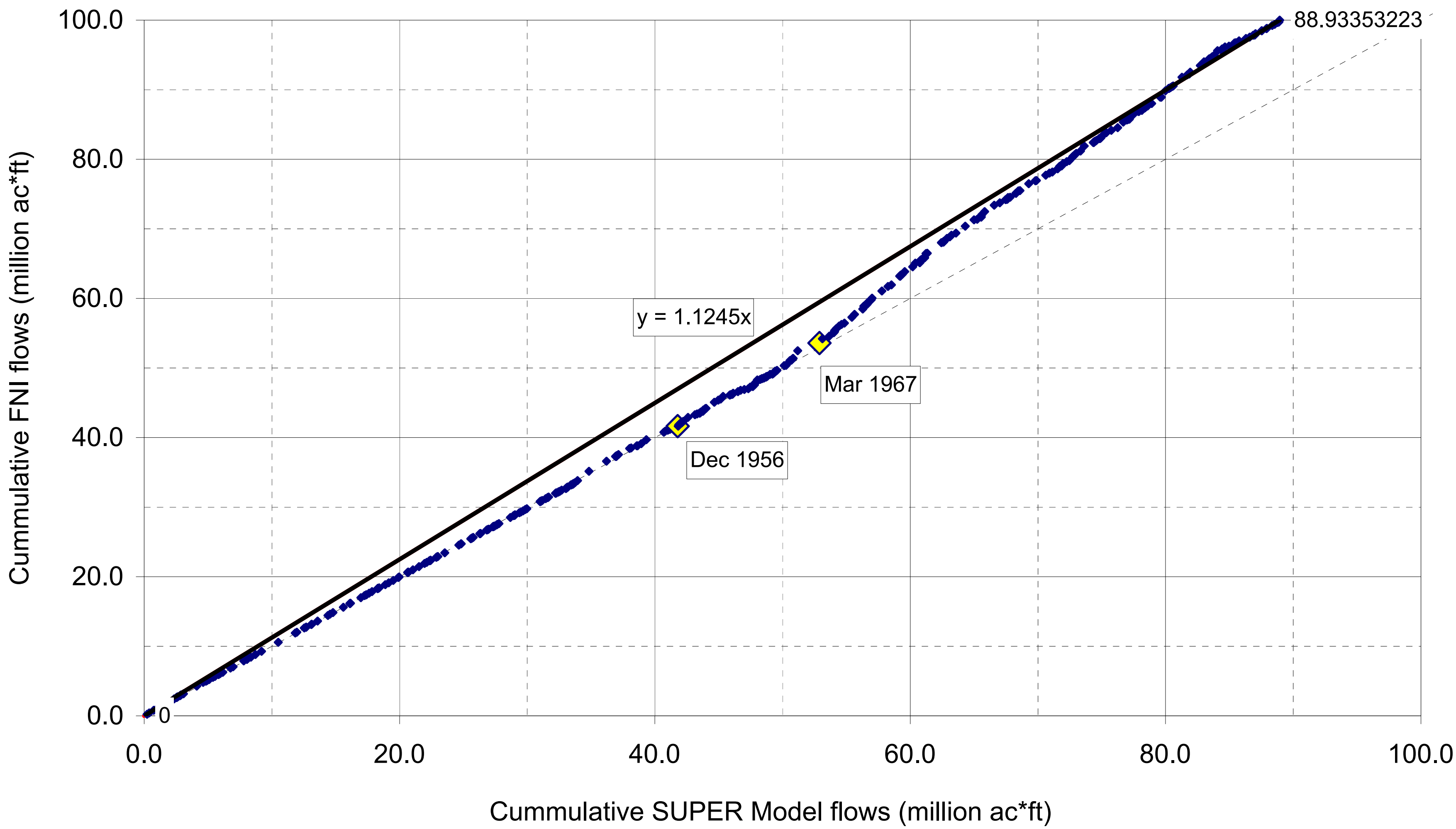


Table C-7
Summary of Comparisons of Lake Wright Patman Flows

Comparison (x vs. y)	Type	Equation	R2	Overlap period	Figure
WAM VS FNI	Scatter	y = 1.03 x + 3529	0.920	1/41-12/86	C-15
	Scatter	y = 1.0425 x	0.917	1/41-12/86	C-15
	Double mass	y = 1.0646 x	-	1/41-12/86	C-16
WAM VS SUPER	Scatter	y = 0.9265 x + 9090	0.918	1/40-12/96	C-19
	Scatter	y = 0.9439 x	0.917	1/40-12/96	C-19
	Double mass	y = 0.9777 x	-	1/40-12/96	C-20
SUPER VS FNI	Scatter	y = 1.046 x + 12415	0.844	1/41-12/86	C-23
	Scatter	y = 1.0704 x	0.843	1/41-12/86	C-23
	Double mass	y = 1.1245 x	-	1/41-12/86	C-24

C-2.1.3 Conclusions

Flows derived from the Sulphur WAM were selected to be the basis for the assessment of system operation of Lakes Wright Patman and Jim Chapman. These flows are distributed on a daily basis using the available Corps SUPER model flows. The reasons for this recommendation are:

- *Consistency with the State permitting process.* It is likely that implementation of the results of this study will require amendments to the water rights for Lakes Wright Patman and Jim Chapman. This process may be somewhat easier if the modeling that is the basis for this amendment is consistent with established TNRCC procedures.
- *Full accounting for existing water rights.* The WAM flows clearly account for all existing water rights in the Sulphur Basin.
- *Changes from historical operation of Lake Wright Patman.* It is likely that the proposed operation of Lake Wright Patman will be substantially different from the historical operation of the reservoir. Inflows that do not include precipitation on the reservoir are appropriate for this type of analysis.

WAM flows are available only through 1996. We extended the flows through 2001 using the double mass relationship between the two datasets illustrated by Figures C-8 and C-20. Flows for Lake Jim Chapman are multiplied by 0.9836 (1.0/1.0167) and flows for Lake Wright Patman are multiplied by 1.023 (1.0/0.9777).

C-2.2 Net Reservoir Evaporation

Evaporation and precipitation rates at each reservoir are combined into a single factor referred to as *net reservoir evaporation*. Net reservoir evaporation is defined as:

Net Evaporation = Evaporation – Precipitation + Effective Runoff

Where

Evaporation is the measured historical evaporation rate

Precipitation is the measured historical precipitation

Effective Runoff is the amount of precipitation that would have contributed to streamflow if the reservoir had not been in place.

We propose developing net evaporation rates on a monthly basis and distributing these rates evenly for each day in the month.

The most complete source of historical evaporation rates is the Texas Water Development Board (TWDB) monthly evaporation quadrangle data. Monthly evaporation at each reservoir is a weighted average of adjacent quadrangles data at each reservoir site. Weighting factors are calculated based on the distance from the reservoir to the center of each quadrangle. These data are available through the year 2000. The data is extended using pan evaporation data from the reservoirs.

Precipitation is based on gages at reservoirs when available. In months where precipitation data are unavailable or incomplete, TWDB quadrangle precipitation is used.

Effective runoff is based on available data from nearby gages on small watersheds. If local gage data are not available, effective runoff is based on incremental naturalized flows. Table C-8 lists data sources for effective runoff development. Flow data is divided by the drainage area of the subbasin to get unit runoff.

Table C-8
Sources for Effective Runoff Calculations

USGS Gage Number	Flow Source and Location	Drainage Area (mi^2)	Period of Record
07342500	Naturalized flows for the South Sulphur River at Cooper	537	1/40 to 12/96
07342480	Historical flows Middle Sulphur River at Commerce	44.1	10/91 to present
07344200 and 07344000	Incremental naturalized flows between Sulphur River near Darden and Lake Wright Patman	669	1/40 to 12/96
07346140	Historical flows Frazier Creek nr Linden	48.0	12/64 to 9/91

C-3.0 Reservoirs

Tables 2-2 through 2-6 in Chapter 2 contain pertinent data on Lakes Chapman and Patman, respectively. These data were derived from information provided by the Corps.

C-3.1 Area Capacity Relationships

The Corps provided area and capacity data for Lakes Chapman and Patman (see Tables D-3 and D-4 in Appendix D). The Lake Jim Chapman survey is the original area capacity relationship for the reservoir, which was closed in 1991. The Texas Water Development Board conducted a volumetric survey of the conservation storage of Lake Wright Patman in 1997. The Corps provided area capacity information for the area above 230 feet. We propose using the existing area capacity relationships without adjustment for sedimentation.

C-3.2 Reservoir Calculations

Reservoir end-of-day content will be based on the following equation:

Cont1 = Cont0 + Runoff + Makeup – Demand – Evaploss – Release– Spill

Where

Cont1 is the end-of-day content for the current time step

Cont0 is the end-of-day content from the previous time step

Runoff is the amount of inflow into the reservoir during the current day

Makeup is any external amount of water coming into the reservoir from another source (namely pumping from Lake Wright Patman to Lake Jim Chapman)

Demand is the amount of water diverted from the reservoir for beneficial use

Evaploss is the calculated evaporative loss for the current time step (net evaporation multiplied by area)

Release is the controlled amount of water released downstream through the dam

Spill is any uncontrolled amount of water going over the dam's spillway

Because the end-of-period content is dependent upon the evaporation, which is a function of the change in content, the model will iterate the calculation until a stable solution is found.

C-3.3 Lake Jim Chapman Operation

There are several operating criteria given in the June 1999 Corps publication *Jim Chapman Lake Cooper Dam Water Control Manual Chapter 7*[4]. Table C-9 is a summary of current release rules from the manual. Releases are set by the elevation of the reservoir at the beginning of the current daily time step. When the reservoir is in the flood pool, the amount of the release is limited to the volume of water required to bring the reservoir to the top of conservation storage at the end of the day as well as the criteria in Table C-9. Based on information from the SUPER model, releases do not change by more than 1,500 cfs per day[3]. Releases when the reservoir is below 447.5 ft are reduced if the release will cause downstream flows to be greater than maximum flows at the gages listed in Table C-10. Flows above 447.5 are released according to the spillway rating curve in Table C-11.

Table C-9
Current Lake Jim Chapman Operational Releases[4]

Reservoir Elevation	Minimum Release	Maximum Release
Below 440.0 ft.	5 cfs or the amount required to meet downstream water rights, whichever is greater	None, subject to downstream control
440.0 ft to 440.4 ft	50 cfs plus inflow or amount to bring reservoir to 440.0 ft	3,000 cfs, subject to downstream control
440.4 ft to 441.0 ft	1,000 cfs plus inflow	3,000 cfs, subject to downstream control
441.0 ft to 446.2 ft	3,000 cfs	3,000 cfs, subject to downstream control
446.2 ft to 447.5 ft	Calculated from spillway rating curve plus amount that will not exceed downstream control	6,000 cfs
Above 447.5 ft	Calculated from spillway rating curve	Calculated from spillway rating curve

Table C-10
Downstream Control for Jim Chapman Releases[4]

Control Location	Maximum Flow
South Sulphur River near Cooper	6,000 cfs
Sulphur River near Talco	34,000 cfs
Red River at Shreveport	Not modeled

Table C-11
Jim Chapman Spillway Rating Curve[3,4]

Reservoir Elevation (ft)	**Discharge** (cfs)	**Reservoir Elevation** (ft)	**Discharge** (cfs)
446.2	0	447.6	3,870
446.3	72	447.8	4,774
446.4	202	447.95	5,500
446.5	372	448.2	6,707
446.6	573	448.4	7,726
446.7	800	448.6	8,790
446.8	1,052	448.8	9,896
446.9	1,326	450.1	18,000
446.96	1,500	455.0	70,000
447.2	2,291	459.5	132,400
447.4	3,041		

The control manual also gives maximum flows for the Red River at Shreveport gage. However, because the modeling approach does not include flows downstream of Lake Wright Patman, we propose that downstream releases not be limited by flows at the Shreveport gage. This assumption is discussed under the section on Lake Wright Patman operation.

There are three operational criteria in the Lake Jim Chapman manual that we did not include in the model:

- *Balancing flood storage with other reservoirs in the Red River Basin.* Storage in reservoirs in the Red River Basin other than Lake Wright Patman is not included in the model. We propose not to include balancing of flood storage.
- *Mosquito control.* The manual specifies that releases may be increased above 5 cfs to maintain a recession rate of 0.2 foot in a 10-day period between May and October for mosquito control. This operation appears to be optional. We propose that mosquito control operation not be included in the model because the focus of this study is primarily on water supply.
- *Pool accounting procedures.* The manual gives the procedures for dividing storage between the various water rights holders in the reservoir. The pool accounting system is unrelated to increasing water supply from Lakes Wright Patman and Jim Chapman and this study will not identify beneficiaries of additional water supply from system operation. Therefore, we propose that the pool accounting procedures not be included in the model.

C-3.4 Lake Wright Patman Operation

The Corps operates Lake Wright Patman with a variable conservation pool elevation. There are two curves governing operation:

- The *interim curve*, which is the curve that currently governs reservoir operation and
- The *ultimate curve*, which is the curve proposed in the Corps contract with the City of Texarkana.

Figure 4-3 in Chapter 4 is an illustration of these two pools. The ultimate curve has never been implemented pending evaluation of the impacts of changing the reservoir's operation.

The model is capable of simulating a variety of rule curves, zones and release options, including both the interim and ultimate curves. Constant-level operation is considered as well. Rule curves are implemented by entering user-specified control dates and releases associated with the zone just below the curve. All releases are based on the elevation at the beginning of each time step.

Simulation of the interim operation is straightforward. Releases are calculated assuming that the actual inflow, demand and evaporation for the current time step are known beforehand. In other words, the actual inflow and evaporation rates for each day are used in the calculations. If the reservoir is above the top of conservation storage, releases are set to the quantity required to bring the reservoir to the top of conservation storage or 10,000 cfs, whichever is less. If the reservoir begins the day at or below the top of conservation storage and the current inflow and evaporation will not cause the reservoir to go above the top of conservation storage, the release is set to either 10 cfs or 96 cfs, depending on the time of year (see Figure 4-3). If inflows will cause the reservoir to go above top of conservation storage, then the release is set to the amount that would keep the reservoir at the top of conservation storage or 10,000 cfs, whichever is less. For the period from May 18 through November 1, the model assumes either a 96 cfs release or a 10 cfs release. The model does not calculate the amount to bring the reservoir to the dotted line in Figure 4-3 or ramp up or down in the transition from 10 cfs to 96 cfs. If a 96 cfs release causes the reservoir to go below the dotted line in Figure 4-3, the release is not reduced from 96 cfs to 10 cfs until the next time step. Similarly, if the reservoir begins the time step below the dotted line and it will go above the dotted line during the time step, the flow is not increased to 96 cfs until the next time step.

Modeling of the ultimate curve is somewhat more problematic, since the Texarkana contract does not specify whether the elevations correspond to beginning-of-month elevation or end-of-month elevation, and there are no releases specified in the contract. The interpretation used in this study was for the top of conservation to be at the specified elevation at the end of the month through mid-June and at the beginning of the month for the rest of the year. This curve never exceeds the monthly maximum storage. The transition from 96 cfs to 10 cfs was retained from the interim curve. This curve is illustrated in Figure 4-6.

As part of the evaluation of potential yield options, we considered taking water from the reservoir below elevation 220.0 feet NVGD. This allows a considerable increase in potential supplies from the system.

When the reservoir is above conservation storage the Lake Wright Patman control manual specifies three main control criteria:

- Changes in release rates will cause a maximum change in tailwater elevation of 4 feet

- Releases will be reduced to prevent flooding at Shreveport (stages above 31 feet)
- The maximum release is 10,000 cfs

FNI did not have sufficient information to calculate tailwater elevations for releases from the reservoir. Tailwater elevations may depend upon downstream conditions as well, and conditions downstream of Lake Wright Patman are outside the area of interest. For the purpose of this study, we assume that the maximum change in release rate is 4,000 cfs based upon parameters from the SUPER model.[3]

Releases from Lake Wright Patman are not limited by the stage at Shreveport. If historical flows below Lake Wright Patman prevented release of floodwaters from the reservoir, that water could potentially be used for water supply. Therefore, assuming that releases of floodwaters from Lake Wright Patman are not limited by downstream conditions gives a conservatively low estimation of potential water supply from the system. Also, assuming that floodwaters are always released does not make the supply from Lake Wright Patman dependent upon a repeat of historical downstream conditions, which may be substantially different depending upon upstream development or changes in operation. However, this approach may slightly underestimate the impact of changes in operation on the White Oak Creek Wildlife Management Area by occasionally overestimating the amount of water that would be released from the reservoir.

The Lake Wright Patman operation releases the amount of water required to bring the reservoir back to the top of the rule curve. Releases are limited to a maximum of 10,000 cfs with a maximum daily change of 4,000 cfs. Actual releases are also limited by the minimum and maximum curves given in Table C-12, which are derived from data from the SUPER model. The limits in Table C-12 are likely only to apply to releases below about 223 feet. Based on the data in Table C-12, the outflow works will release less than 10,000 cfs below reservoir elevations of about 222.9 feet.

Table C-12
Minimum and Maximum Releases from Lake Wright Patman[3]

Reservoir Elevation (ft-msl)	**Patman Maximum Release** (cfs)	**Patman Minimum Release** (cfs)
200	0	0
220	8,200	0
230	14,500	0
235	17,500	0
240	20,000	0
250	24,000	0
259.5	27,500	0
261	29,000	1,300
263.7	34,200	5,400
265	37,200	8,000
265.5	38,500	9,500
268.5	47,800	15,700
272	61,900	31,400
275	76,300	44,000
280	101,800	68,000

C-4.0 Routing Between Lake Jim Chapman and Lake Wright Patman

We developed modified daily flows at four control points below Lake Jim Chapman:

- The South Sulphur near Cooper
- Sulphur River near Talco
- The U.S. Highway 67 bridge in the White Oak Creek WMA
- Lake Wright Patman.

These flows do not include flows originating above Lake Jim Chapman or spills and releases from Lake Jim Chapman. The model calculates outflows from Lake Jim Chapman based upon the operating rules built into the model (see the section on Lake Jim Chapman operation). These flows are then added to the flows at the downstream control points, subject to time delays and/or storage along the reach. The South Sulphur River near Cooper and Sulphur River below Talco are part of the flood release operations from Lake Jim Chapman, which are designed to minimize flooding at these locations. The Highway 67 bridge was selected to estimate the impacts of changes in operation on the White Oak Creek WMA.

The original Scope of Services for the project specified the downstream edge of the White Oak Creek WMA as the point at which to evaluate impacts on the WMA. FNI recommended moving this point to the Highway 67 bridge a few miles upstream. The bridge is at or near the former location of the Sulphur River near Darden gage. This location has several years of recorded historical flows to aid in development of streamflows at that location. It is also likely that this location has a more stable channel, making estimates of flow at this location valid over a longer period of time.

The Corps provided data on two methods that could be used to route outflows from Lake Jim Chapman to the intervening points:

- A Modified Muskingum method used in the SUPER model
- Travel times developed by the National Weather Service

Table C-13 gives the parameters for the Modified Muskingum method used in the SUPER model. Using these parameters, 25% of the outflow from Lake Jim Chapman is added to the Lake Wright Patman inflows four days after the flow leaves the reservoir, 29% arrives one day later and so on. Parameters were not available for the Highway 67 bridge. Values for the Highway 67 bridge were interpolated between the Talco and Lake Wright Patman values.

Table C-13
Modified Muskingum Routing from COE SUPER Model[3]

Location	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Cooper Outflow	100%	-	-	-	-	-	-	-
Sulphur R at Talco	34%	46%	15%	5%	-	-	-	-
Lake Wright Patman	-	-	-	25%	29%	26%	20%	-

Table C-14 gives incremental and cumulative travel time based on data from the National Weather Service, as provided by the Corps. One way to use these parameters is to add the entire outflow from Lake Jim Chapman to the downstream point delayed by the number of days given in the table. For example, a release of 15,000 cfs from Lake Jim Chapman would be added to the flows at Lake Wright Patman 6 days after it is released from the reservoir. These travel times have the advantage of being available at all of the required control points. However, the application of these times is somewhat problematic. If outflows from Lake Jim Chapman are below 13,000 cfs one day and above 13,000 cfs the next day, flows from these two consecutive days would reach downstream points on the same day. Conversely, separation of flows could occur when outflows from Lake Jim Chapman fall from above 13,000 cfs to below 13,000 cfs on consecutive days. However, based on the operating criteria for Lake Jim Chapman, it appears to be unlikely that releases from the reservoir would exceed 13,000 cfs very many times during the simulation.

Table C-14
NWS Travel Times for the Sulphur River Basin[5]

Upstream Point	Downstream Point	Flow Range (cfs)	Incremental Travel Time (hours)	Incremental Travel Time (days)	Cumulative Travel Time (days)
Lake Jim Chapman	S Sulphur R at Cooper	Not specified	8	0.3	0
S Sulphur R at Cooper	Sulphur R at Talco	Not specified	40	1.7	2
Sulphur R at Talco	Sulphur R at Darden	0-13,000	78	3.3	5
		13,000 to 23,000	56	2.3	4
		over 23,000	54	2.3	4
Sulphur R at Darden	Wright Patman Lake	0-13,000	50	2.1	7
		13,000 to 23,000	50	2.1	6
		over 23,000	50	2.1	6

We did not consider channel losses when routing water from Lake Jim Chapman to Lake Wright Patman. Losses are most likely minimal and would have little impact on reservoir yields.

The Modified Muskingum method was used in the model. Parameters for the Darden gage were estimated by interpolating between the values for the Talco gage and Lake Wright Patman.

C-5.0 Pumping from Lake Wright Patman to Lake Jim Chapman

The model uses a zone system to determine delivery from Lake Wright Patman to Lake Jim Chapman, a process that Freese and Nichols has successfully used in many system operation models. The conservation and flood storage of each reservoir is divided into three to five zones that may vary seasonally. The user assigns pumping rates to each zone combination. As a starting point, we assume a minimum pumping rate of 60 mgd, which can be increased in 30 mgd increments. We assume that it will take one day for the water to be transferred from one reservoir to the other. Maximum pumping rates will be determined in the modeling process. Minimum pumping rates, pumping level increments and maximum pumping rates are refined as the study progresses to maximize the yield of the system.

An analysis of the facilities, construction costs or operating costs of a delivery system from Lake Wright Patman to Lake Jim Chapman is not part of the scope of work for this study.

C-6.0 Demands

There exist five types of demands in the model:

- Municipal local demands at Lake Wright Patman
- Industrial local demands at Lake Wright Patman
- Local demands at Lake Jim Chapman
- System demands diverted from Lake Jim Chapman
- Interruptible system demands diverted from Lake Jim Chapman

The local demands at the reservoirs correspond to current water diversions and contracts from the reservoirs and are met on a reliable basis. Industrial demand is modeled separately for Lake Wright Patman because the reservoir has a large industrial demand with a significantly different diversion pattern from Texarkana's municipal demands. Local demands from Lake Jim Chapman are assumed to be primarily municipal. System demand corresponds to the reliable increase in supply made available by operating the reservoirs in a coordinated way. Interruptible system demand is the amount of water that may be available from the reservoir system on a less than 100 percent reliable basis. System demands are assumed to be primarily for municipal supply.

We make the simplifying assumption that all system demands (reliable and interruptible) are diverted from Lake Jim Chapman. Pumping from Lake Wright Patman to Lake Jim Chapman backs up the supply. However, we assume that pumping from one reservoir to another is a function of the zone combination of the reservoirs, so pumping is indirectly impacted by demand.

The model uses annual demands distributed based on typical monthly demand patterns for each demand. The monthly demands are then evenly distributed to each day in the month. The primary source of demand patterns is the Sulphur WAM. Table C-15 gives the demand patterns from this study. System demands are assigned the same pattern as the Lake Jim Chapman local demands.

Table C-15
Demand Patterns from the Sulphur WAM[1]

Owner	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
City Of Commerce	8.48%	8.04%	8.36%	7.58%	7.62%	8.34%	9.60%	9.50%	8.55%	8.83%	7.80%	7.30%
Sulphur River MWD	8.48%	8.04%	8.36%	7.58%	7.62%	8.34%	9.60%	9.50%	8.55%	8.83%	7.80%	7.30%
City Of Irving	6.51%	6.07%	6.48%	6.97%	8.02%	9.51%	11.61%	11.76%	10.34%	9.05%	7.15%	6.53%
North Texas MWD	7.28%	6.53%	5.90%	8.57%	6.89%	8.76%	12.32%	14.67%	11.31%	8.67%	5.18%	3.93%
Average Chapman	*7.26%*	*6.69%*	*6.63%*	*7.79%*	*7.45%*	*8.94%*	*11.48%*	*12.52%*	*10.37%*	*8.84%*	*6.44%*	*5.58%*
Texarkana Municipal	8.01%	7.29%	7.71%	7.77%	8.49%	8.49%	9.42%	9.96%	8.98%	8.25%	7.47%	8.16%
Texarkana Industrial	7.97%	7.72%	8.76%	8.13%	8.27%	8.72%	8.51%	8.88%	8.31%	8.69%	8.22%	7.81%

C-7.0 Impact on the White Oak Creek Wildlife Management Area

The Scope of Services for this study calls for a qualitative analysis of the impact of operation policies on the White Oak Creek WMA. Flows at the management area are output from the model for further analysis. Existing backwater models from Lake Wright Patman was used to develop a family of rating curves that determine the approximate elevation of the flows at the WMA based on flow and the elevation in Lake Wright Patman. These rating curves are given in Table C-16. Elevations were estimated by interpolating between these curves. Table C-17 gives a relationship between elevations and area in the White Oak Creek WMA. These data may be used to make an evaluation of inundation frequency at the management area. See Plate 1 for a map showing the areas inundated at the WMA.

Table C-16
Relationship between Lake Wright Patman Elevation,
Flow at Highway 67, and Water Surface Elevation at Highway 67

Flow (cfs) / Lake Elev. (ft)	0	269	1,214	2,290	59,000	151,000
215	221.6	224.04	227.41	229.34	247.97	254.51
221.6	221.6	224.04	227.41	229.34	247.97	254.51
223	223	224.04	227.41	229.34	247.97	254.51
228.64	228.64	228.64	228.74	229.34	247.97	254.51
230	230	230	230.05	230.17	247.97	254.51
235	235	235	235	235.02	247.97	254.51
240	240	240	240	240	247.97	254.51
250	250	250	250	250	250.42	254.51
255	255	255	255	255	255.14	255.88
260	260	260	260	260	260.07	260.44
265	265	265	265	265	265.03	265.2

Table C-17
Relationship between Water Surface Elevation and Inundation at the White Oak Creek WMA

Water Surface Elevation (ft)	**Inundated Area** (acres)
215	0
225	0
230	496
240	3,800
250	12,134
260	18,832
270	22,572
280	23,415

C-8.0 Red River Compact

The study area is located in Subbasin 4 of the Red River Compact. According to Section 5.04(b), the "State of Texas shall have the free and unrestricted use" of water above Lake Wright Patman[6]. Therefore the Red River Compact does not affect this study.

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[1] R.J. Brandes Company: *Water Availability Modeling for the Sulphur River Basin*, prepared for the Texas Natural Resource Conservation Commission, 1999.

[2] Ralph A. Wurbs: *Reference and Users Manual for the Water Rights Analysis Package (WRAP)*, Texas Water Resources Institute, Report T-180, 2001.

[3] Ron Hula, USACOE, personal communication.

[4] U.S. Army Corps of Engineers Fort Worth District, *Jim Chapman Lake Cooper Dam Water Control Manual Chapter 7*, June 1999.

[5] Paul Rodman, U.S. Army Corps of Engineers Fort Worth District, personal communication

[6] Texas Water Code Chapter 46. Available online at ftp://capitol2.tlc.state.tx.us/pub/statues/wpd/waW1460.zip.

Appendix D

Hydrologic Data

Table D-1a
Lake Jim Chapman Monthly Reservoir Inflows
Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	157	2,591	2,192	41,182	24,177	20,757	13,475	254	541	44	28,646	53,201	187,217
1941	14,984	21,785	58,666	52,849	77,251	27,765	8,372	2,194	746	518	4,162	10,105	279,397
1942	1,657	4,729	15,360	179,795	29,314	36,037	1,983	2,728	9,914	397	7,532	25,271	314,717
1943	159	2,162	42,719	6,023	19,250	36,207	163	0	0	64	1,138	4,401	112,286
1944	11,510	35,475	51,579	12,962	109,360	15,770	1,035	2,993	525	0	4,957	35,495	281,661
1945	15,263	78,239	117,209	33,357	13,255	54,969	27,375	91	7,913	42,819	2,935	22	393,447
1946	33,577	73,567	29,219	22,176	102,055	37,899	452	13,139	215	169	114,844	25,566	452,878
1947	7,921	363	16,126	20,417	27,971	5,195	2	6,048	306	210	16,923	51,799	153,281
1948	36,297	33,004	38,537	15,897	65,630	2,776	3,608	48	0	18	0	1,983	197,798
1949	94,605	64,270	40,333	15,251	15,372	10,053	4,667	1,323	898	50,035	229	3,000	300,036
1950	54,320	148,397	6,949	7,326	84,192	17,806	8,271	1,292	71,768	124	5	22	400,472
1951	772	41,839	574	266	4,023	112,720	9,294	0	0	701	1,106	271	171,566
1952	3,628	1,724	4,727	97,509	31,100	5,480	0	0	0	0	14,339	20,596	179,103
1953	10,962	1,046	26,012	96,191	51,272	6	10,975	492	4	109	7,882	27,172	232,123
1954	39,991	6,148	101	11,074	40,646	3,596	0	0	0	46,810	11,150	509	160,025
1955	1,199	21,147	21,361	16,605	8,148	45	2,301	3,026	767	1,421	0	0	76,020
1956	0	19,945	9	360	21,944	1,337	0	0	0	0	2,310	1,873	47,778
1957	6,198	14,589	46,978	239,689	191,838	64,410	365	3,920	28,175	27,829	137,451	10,150	771,592
1958	31,827	764	50,164	87,713	131,227	27,217	14,745	56	3,014	521	767	660	348,675
1959	995	11,735	7,403	6,198	2,056	8,371	19,356	1,433	1,286	19,519	16,877	62,342	157,571
1960	45,783	15,204	9,971	2,046	14,701	21,099	10,774	1,495	7,303	18,526	691	104,079	251,672
1961	49,125	16,882	37,003	8,964	978	13,149	3,413	1,288	4,298	41	13,835	31,476	180,452
1962	12,530	9,650	5,189	23,708	6,697	33,092	18,427	3,129	63,494	9,263	37,887	4,367	227,433
1963	11,903	187	5,530	7,484	11,287	1,064	15,355	20	0	0	0	0	52,830
1964	0	67	8,655	21,242	16,615	22,436	0	0	20,551	387	33,127	1,096	124,176
1965	22,643	108,689	1,271	520	110,421	3,329	18	0	5,614	16	633	0	253,154
1966	646	25,412	793	186,387	90,419	40	444	2,182	5,987	1,708	48	613	314,679
1967	155	62	1,830	51,382	44,312	71,843	1,090	68	21,625	33,980	19,203	41,198	286,748
1968	32,320	15,180	94,469	50,675	75,346	37,789	25,153	3,925	19,512	2,694	23,796	37,007	417,866
1969	57,752	93,958	64,931	21,808	166,999	2,310	0	0	0	5,227	2,250	26,860	442,095

Table D-1a (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970	9,507	54,400	81,130	55,969	5,777	3,228	0	0	8,289	41,799	4,072	1,453	265,624
1971	1,008	7,729	3,570	31	46	67	244	9,566	1,699	118,147	735	180,302	323,144
1972	4,541	621	5,297	205	680	734	0	0	152	12,898	36,338	16,037	77,503
1973	29,563	31,577	81,550	99,535	12,661	33,310	649	188	69,848	72,337	91,103	34,286	556,607
1974	70,736	3,624	8,534	79,485	13,374	104,294	47	463	68,367	8,764	132,588	62,828	553,104
1975	15,287	129,699	57,564	41,985	74,209	80,300	1,600	165	0	0	0	141	400,950
1976	0	34	5,204	52,916	33,462	12,475	36,447	392	4,088	21,921	3,259	46,641	216,839
1977	26,285	55,659	127,536	47,229	1,741	15,481	239	3,138	770	0	4,705	757	283,540
1978	4,510	33,569	31,178	1,998	4,723	6,583	0	0	0	0	3,199	2,450	88,210
1979	59,377	29,090	52,850	32,380	122,481	42,547	2,156	4,763	391	99	317	18,064	364,515
1980	31,332	20,056	186	8,273	25,475	837	0	0	4,405	5,446	124	19,182	115,316
1981	64	40	15,328	1,201	30,000	159,239	1,459	33	0	92,965	40,935	736	342,000
1982	1,079	13,339	7,924	9,468	215,567	39,153	6,869	292	451	0	11,767	59,866	365,775
1983	1,668	79,740	49,956	3,719	14,854	2,908	21,075	46	0	379	739	294	175,378
1984	282	18,618	92,152	13,356	5,604	205	0	0	0	35,456	12,849	71,717	250,239
1985	11,299	20,187	77,793	44,774	66,332	8,510	269	0	0	3,545	60,605	44,030	337,344
1986	84	43,176	244	47,458	16,443	49,893	4,536	0	3,641	6,431	56,157	17,687	245,750
1987	24,078	25,286	83,004	640	10,313	11,606	244	0	10,426	8,955	144,787	109,681	429,020
1988	23,702	20,197	16,227	21,515	5	89	36,064	0	2,074	4,726	39,882	14,515	178,996
1989	38,478	68,643	28,949	4,308	61,986	87,000	47,566	1,660	919	74	202	40	339,825
1990	11,138	60,050	125,923	79,867	128,232	32,557	0	1,368	470	2,873	14,129	14,182	470,789
1991	55,820	25,144	12,270	53,761	41,420	21,370	139	0	0	4,697	55,016	65,940	335,577
1992	44,489	41,013	86,461	8,996	112,598	75,605	58,333	18,141	1,411	2,654	2,199	46,422	498,322
1993	21,728	86,033	46,915	70,762	17,527	2,086	3,520	4,113	2,800	94,803	32,130	89,290	471,707
1994	15,718	32,153	42,524	12,422	78,924	4,925	51,896	5,334	6,922	20,570	81,699	57,622	410,709
1995	55,567	4,331	52,966	51,946	133,234	32,363	2,862	2,417	3,370	0	1,869	0	340,925
1996	3,887	2,037	3,611	6,363	2,088	5,552	5,329	5,496	2,281	11,631	140,317	20,393	208,985
1997	8,901	161,651	62,681	103,353	10,052	38,743	0	4,217	0	8,051	4,258	108,177	510,084
1998	107,285	46,973	52,620	8,102	2,400	2,913	1,071	217	7,706	57,278	59,237	136,940	482,742
1999	68,994	3,733	14,335	22,508	27,300	11,313	0	0	1,440	1,782	1,448	10,809	163,662
2000	4,003	8,930	37,329	14,425	26,865	86,752	527	470	0	5,117	126,214	98,027	408,659
2001	45,729	150,951	121,444	50,852	14,657	3,114	1,029	5,852	20,431	12,848	5,189	167,120	599,216
Average	22,500	34,631	36,953	38,498	46,756	26,941	7,827	1,927	8,013	14,829	26,981	33,819	299,674

Table D-1b
Lake Wright Patman Monthly Reservoir Inflows
Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	193	8,754	8,706	310,167	317,269	343,114	354,755	550	1,844	234	187,004	515,847	2,048,437
1941	302,701	161,524	337,978	213,223	910,742	675,998	255,822	18,130	2,774	37,940	94,103	201,133	3,212,068
1942	34,122	79,347	206,437	936,668	646,479	201,094	5,231	2,865	8,995	951	20,962	64,198	2,207,349
1943	125,285	21,321	305,960	185,897	44,021	234,967	14,298	649	1,201	10,073	4,733	24,375	972,780
1944	83,048	169,738	697,371	232,580	813,530	298,224	1,488	1,324	29,595	363	68,687	209,876	2,605,824
1945	447,216	443,972	1,379,491	1,710,748	109,587	597,222	155,852	8,859	12,112	349,053	29,924	5,527	5,249,563
1946	441,865	822,710	126,126	263,084	705,512	556,403	9,423	7,520	4,026	1,714	839,506	317,511	4,095,400
1947	130,282	19,284	212,274	254,419	467,630	17,216	4,218	1,590	1,868	602	64,433	410,877	1,584,693
1948	295,312	349,147	416,864	64,123	637,689	33,553	7,810	5,124	604	865	1,475	2,894	1,815,460
1949	278,294	404,497	494,156	194,134	218,536	61,851	10,055	5,309	4,707	374,002	101,946	60,801	2,208,288
1950	520,490	1,111,182	204,133	18,250	743,618	71,464	29,735	77,038	583,537	20,746	2,852	1,431	3,384,476
1951	49,793	520,266	83,744	31,716	54,979	231,694	39,124	4,328	10,367	7,880	25,580	57,882	1,117,353
1952	186,162	79,564	125,978	970,020	254,318	86,139	12,385	3,590	61	58	41,057	308,813	2,068,145
1953	142,679	230,129	164,067	192,106	1,047,240	7,339	32,740	2,903	8,436	702	13,265	69,356	1,910,962
1954	246,230	157,512	20,885	62,256	596,065	37,834	421	44	45	93,585	26,160	14,678	1,255,715
1955	18,382	60,883	175,762	272,954	29,640	6,336	40,313	12,856	36,118	90,887	950	1,746	746,827
1956	1,692	341,669	10,600	3,839	115,172	4,074	2,822	1,659	1,308	1,335	18,453	2,253	504,876
1957	45,973	117,423	331,352	1,241,868	1,488,015	754,278	2,080	4,211	73,834	173,035	889,885	81,261	5,203,215
1958	332,743	9,553	275,461	547,942	1,153,809	155,375	176,975	5,929	63,544	8,107	77,149	15,400	2,821,987
1959	17,105	247,806	145,913	126,967	14,702	206,644	205,666	31,132	17,859	107,448	93,209	644,645	1,859,096
1960	428,406	99,596	106,898	7,092	39,556	85,141	155,371	23,180	172,316	197,332	36,961	918,926	2,270,775
1961	278,718	166,893	357,994	317,160	41,267	73,284	62,904	7,367	11,479	4,708	52,771	331,735	1,706,280
1962	239,864	242,860	246,693	195,161	129,245	83,142	45,544	6,811	115,435	107,351	172,530	62,829	1,647,465
1963	99,110	11,837	123,014	56,520	106,217	8,463	19,286	147	48	562	0	3,583	428,787
1964	3,556	10,049	59,054	289,359	140,979	47,197	0	11,445	67,722	22,067	73,070	55,058	779,556
1965	98,538	630,483	56,684	31,242	370,997	30,948	858	1,574	3,625	27	23	4,176	1,229,175
1966	12,885	224,327	9,189	972,215	1,076,626	2,910	6,146	13,402	40,994	96,747	871	14,440	2,470,752
1967	8,015	11,687	34,095	673,298	341,963	562,764	112,414	558	35,637	95,012	342,624	396,282	2,614,349
1968	216,844	140,827	567,686	215,159	590,208	216,172	44,497	13,028	66,337	11,903	141,885	201,776	2,426,322
1969	172,091	675,115	412,760	216,688	697,298	10,020	106	2,590	7,811	1,080	9,138	76,906	2,281,603
1970	72,042	269,932	606,079	434,382	130,938	25,375	2,899	4,267	13,489	120,290	43,696	21,717	1,745,106
1971	17,901	70,585	58,014	7,882	24,905	4,534	48,123	85,585	2,246	281,380	100,119	1,126,680	1,827,954
1972	143,791	10,046	28,997	9,282	8,247	4,988	7,307	975	9,471	33,638	226,922	226,865	710,529

Table D-1b (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	199,431	292,188	770,906	792,079	168,062	326,310	7,709	0	136,740	263,688	792,327	376,113	4,125,553
1974	463,007	101,263	47,185	91,727	145,005	501,052	337	2,021	248,970	109,610	704,248	487,229	2,901,654
1975	85,219	747,669	364,255	175,746	439,664	136,982	15,040	6,669	65	54	5,630	2,681	1,979,674
1976	10,121	13,242	148,766	158,485	288,288	219,667	287,028	74	14,973	24,488	11,921	97,466	1,274,519
1977	102,405	337,729	521,544	476,818	35,276	20,833	587	1,957	26	63	47,484	15,466	1,560,188
1978	52,642	106,823	273,914	18,695	28,975	11,803	28	0	18	0	33,047	13,883	539,828
1979	523,118	242,222	337,107	431,980	870,241	340,789	28,926	77,503	17,362	1,136	12,205	326,220	3,208,809
1980	293,754	294,081	42,233	219,925	143,074	41,602	995	1,230	13,654	30,098	17,786	59,738	1,158,170
1981	8,122	37,616	52,158	14,743	325,936	608,498	62,767	142	397	439,611	226,704	9,962	1,786,656
1982	34,382	119,412	96,452	77,839	764,630	372,924	108,618	16,409	321	1,238	159,073	812,443	2,563,741
1983	19,928	238,850	323,201	66,632	84,473	23,447	58,851	0	0	8	1,351	26,321	843,062
1984	17,492	93,865	329,676	188,494	75,778	0	0	0	0	259,948	248,958	416,722	1,630,933
1985	90,362	307,990	476,931	304,755	242,266	65,993	3,677	13	0	4,237	94,383	410,401	2,001,008
1986	13,132	340,259	35,809	407,198	178,955	216,843	79,441	0	3,129	13,915	113,874	165,926	1,568,481
1987	142,259	164,408	630,709	27,003	15,764	25,857	9,761	0	30,458	36,017	384,758	956,146	2,423,140
1988	246,647	139,495	149,094	123,177	594	0	43,321	484	1,115	2,635	357,630	209,641	1,273,833
1989	176,948	667,145	350,064	157,207	666,737	605,145	207,846	23,435	8,453	65	141	2,534	2,865,720
1990	227,694	324,713	1,102,428	497,150	909,722	193,097	7,210	10,101	10,949	32,329	123,097	263,224	3,701,714
1991	472,448	280,323	171,043	486,939	377,414	37,441	6,721	8,029	8,267	224,310	329,871	927,183	3,329,989
1992	264,140	344,743	605,665	54,910	135,101	191,021	492,363	226,742	41,768	2,499	103,000	600,279	3,062,231
1993	453,866	293,645	566,089	259,381	105,484	28,702	1,113	1,095	3,030	399,566	142,769	554,821	2,809,561
1994	145,419	214,858	442,565	35,223	215,457	62,403	202,300	10,579	9,817	40,953	369,529	468,130	2,217,233
1995	485,102	137,865	225,533	361,419	588,524	72,038	7,362	1,365	16,500	1,223	1,997	4,781	1,903,709
1996	12,488	2,350	12,617	18,698	96,074	51,349	11,170	119,663	54,254	81,577	833,702	269,203	1,563,145
1997	118,502	886,584	609,655	528,659	246,691	146,657	0	10,054	578	16,867	31,304	256,566	2,852,117
1998	840,408	373,039	333,378	41,719	49,015	0	0	2,305	59,195	190,712	110,780	492,654	2,493,205
1999	244,001	180,930	312,314	155,868	91,899	38,333	9,517	0	438	8,016	0	23,996	1,065,312
2000	12,397	31,784	169,327	164,723	360,463	516,766	176,037	0	0	0	543,884	483,557	2,458,938
2001	737,442	953,906	1,126,254	301,091	131,670	77,314	39,536	0	100,081	191,712	31,275	966,869	4,657,150
Average	193,294	261,121	306,730	288,656	352,391	172,075	60,241	14,297	35,323	74,649	155,398	260,510	2,174,685

Table D-1c

Monthy Incremental Flows Lake Chapman to South Sulphur River Near Cooper

Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	0	0	0	3,083	1,990	1,552	839	0	0	0	1,537	4,210	13,211
1941	1,047	1,728	4,657	4,419	6,072	2,328	453	0	40	28	0	543	21,315
1942	0	0	824	14,467	2,217	2,752	106	0	532	0	0	1,357	22,255
1943	0	0	2,893	0	1,383	0	0	0	0	0	0	0	4,276
1944	0	1,904	3,689	904	9,081	927	0	0	0	0	0	1,905	18,410
1945	976	6,565	9,907	2,542	812	4,437	2,037	0	425	3,058	0	0	30,759
1946	2,378	5,988	2,302	1,718	8,519	2,760	0	705	0	0	8,661	2,003	35,034
1947	512	0	1,005	1,722	2,117	0	0	0	0	0	909	3,210	9,475
1948	2,896	2,681	3,035	1,031	5,411	0	194	0	0	0	0	0	15,248
1949	5,868	5,273	3,200	1,228	971	601	251	43	0	3,230	0	0	20,665
1950	4,214	12,185	0	0	6,870	1,239	528	69	5,538	0	0	0	30,643
1951	0	2,503	0	0	216	8,616	499	0	0	38	0	0	11,872
1952	0	0	254	6,761	2,438	294	0	0	0	0	770	1,105	11,622
1953	588	0	1,397	7,606	4,278	0	589	26	0	0	0	1,458	15,942
1954	2,879	330	0	595	3,034	0	0	0	0	2,523	299	0	9,660
1955	0	1,150	1,469	1,220	502	0	124	163	0	76	0	0	4,704
1956	0	1,070	0	0	1,178	0	0	0	0	0	0	0	2,248
1957	0	783	2,523	18,126	15,894	5,112	0	96	1,532	2,190	11,414	697	58,367
1958	2,553	0	3,945	7,233	10,576	2,064	923	0	162	0	41	0	27,497
1959	0	630	397	332	0	449	1,039	77	69	1,048	907	4,977	9,925
1960	3,740	1,152	626	0	793	1,400	581	80	392	1,150	0	8,399	18,313
1961	3,893	1,335	2,955	485	53	0	183	0	231	0	742	2,036	11,913
1962	1,013	654	280	1,802	360	2,465	1,111	0	4,771	691	3,036	235	16,418
1963	787	0	297	402	606	0	824	0	0	0	0	0	2,916
1964	0	0	465	1,140	892	1,205	0	0	1,103	21	1,790	0	6,616
1965	1,249	8,754	0	0	8,617	179	0	0	0	0	0	0	18,799
1966	0	1,364	0	14,128	7,243	0	0	117	322	92	0	0	23,266
1967	0	0	0	2,758	3,238	5,428	58	0	1,161	2,465	1,357	3,298	19,763
1968	2,636	1,118	7,709	4,034	6,107	2,987	1,731	211	1,159	144	1,728	2,915	32,479
1969	4,653	7,636	5,290	1,610	13,705	0	0	0	0	0	0	1,442	34,336
1970	510	3,551	6,572	4,503	310	0	0	0	445	2,267	218	0	18,376
1971	0	363	0	0	0	0	0	514	91	7,801	0	14,823	23,592
1972	244	0	0	0	0	0	0	0	0	693	1,950	861	3,748

Table D-1c (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	1,898	2,500	6,731	8,206	790	2,643	0	0	4,961	5,953	7,382	2,691	43,755
1974	5,768	0	0	6,170	835	8,361	0	0	5,026	661	10,891	5,029	42,741
1975	1,131	10,534	4,606	3,217	6,042	6,435	86	0	0	0	0	0	32,051
1976	0	0	0	2,840	1,974	811	2,836	0	219	1,187	0	3,521	13,388
1977	2,107	4,433	10,370	3,722	0	0	0	0	0	0	0	0	20,632
1978	0	1,802	1,725	0	192	0	0	0	0	0	172	132	4,023
1979	3,197	1,909	4,276	2,458	10,063	3,174	116	256	0	0	0	970	26,419
1980	1,967	1,462	0	444	1,746	0	0	0	236	292	0	1,030	7,177
1981	0	0	823	0	1,610	12,107	79	0	0	6,613	3,165	0	24,397
1982	0	716	425	536	17,759	3,084	369	16	0	0	631	4,289	27,825
1983	0	6,345	3,955	199	949	0	1,162	0	0	0	0	0	12,610
1984	0	1,000	6,511	817	325	0	0	0	0	1,903	690	5,609	16,855
1985	793	1,651	6,364	3,580	5,298	0	14	0	0	190	3,642	3,510	25,042
1986	0	3,232	0	3,579	1,196	3,936	243	0	195	345	3,731	1,351	17,808
1987	1,867	2,024	6,673	0	0	0	13	0	560	481	11,381	9,039	32,038
1988	1,762	1,545	1,260	1,515	0	0	1,964	0	0	0	2,687	1,072	11,805
1989	3,080	5,629	2,273	232	5,009	7,100	3,762	89	49	0	0	0	27,223
1990	598	3,846	10,462	6,462	10,640	2,333	0	0	25	154	759	761	36,040
1991	4,376	1,982	760	4,459	3,273	1,389	0	0	0	252	3,456	5,333	25,280
1992	3,477	3,236	6,942	0	9,044	6,184	4,652	1,040	76	3	118	3,318	38,090
1993	1,616	6,939	3,721	5,653	1,233	0	0	0	150	6,381	2,508	7,149	35,350
1994	1,120	2,503	3,299	893	6,385	264	3,806	287	372	1,123	6,602	4,588	31,242
1995	4,378	233	4,107	4,143	10,902	2,323	154	0	181	0	0	0	26,421
1996	0	0	0	0	112	298	286	295	123	624	9,543	1,550	12,831
1997	1,692	16,114	7,117	6,617	1,440	1,942	515	721	441	44	30	6,802	43,475
1998	12,491	5,512	3,236	1,324	811	754	778	780	559	2,558	4,075	9,884	42,762
1999	5,613	708	1,218	2,236	1,955	194	90	0	0	0	0	95	12,109
2000	14	242	2,030	1,019	4,726	7,722	2,393	8	5	75	19,663	15,955	53,852
2001	8,986	20,334	22,385	10,168	3,567	861	117	1	1,292	3,205	60	21,350	92,326
Average	1,783	2,825	3,015	2,973	3,764	1,915	573	90	523	961	2,041	2,750	23,213

Table D-1d
Monthy Incremental Flows Lake Chapman to Sulphur River Near Talco
Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	101	3,537	3,423	93,692	85,061	86,850	78,014	334	1,266	139	60,799	146,119	559,335
1941	69,200	50,486	114,288	83,433	251,603	156,993	55,485	5,029	1,654	8,055	21,259	48,236	865,721
1942	7,673	19,952	53,280	324,278	153,309	65,068	2,425	1,188	4,801	480	5,088	18,278	655,820
1943	41,728	6,265	97,356	42,623	7,868	80,616	2,905	228	426	3,051	1,877	8,471	293,414
1944	26,627	65,128	189,767	62,051	267,796	69,978	975	841	7,659	183	19,321	75,120	785,446
1945	110,937	160,739	416,898	411,197	36,368	185,387	42,230	2,728	1,055	123,110	10,016	1,792	1,502,457
1946	143,731	257,447	58,080	70,115	257,791	155,427	2,626	2,247	3,799	790	253,003	99,218	1,304,274
1947	37,917	4,936	64,247	77,670	137,032	5,586	314	673	1,946	219	26,588	147,739	504,867
1948	87,885	110,682	123,564	22,740	206,634	8,872	4,116	1,379	178	241	620	908	567,819
1949	126,904	145,915	130,197	51,604	62,410	19,848	4,503	2,370	1,828	141,575	20,769	18,604	726,527
1950	166,983	345,820	55,721	7,223	232,886	22,155	11,549	22,881	165,184	4,734	807	577	1,036,520
1951	13,363	155,696	18,113	8,544	18,206	94,885	14,480	1,107	2,881	4,164	6,832	15,406	353,677
1952	48,570	20,644	37,111	292,109	72,880	20,595	3,683	903	14	9	15,993	97,372	609,883
1953	40,490	55,539	55,905	58,512	299,610	1,768	13,105	1,725	3,467	312	4,841	30,159	565,433
1954	84,374	45,065	5,200	19,434	173,019	10,965	134	12	0	15,845	37,763	3,964	395,775
1955	5,743	24,552	55,005	76,563	11,180	1,826	13,212	5,891	8,277	22,361	249	440	225,299
1956	708	103,314	2,809	1,598	41,206	1,440	740	464	367	0	8,707	1,534	162,887
1957	13,343	33,498	88,937	397,202	521,206	272,768	463	2,434	27,904	38,742	263,646	24,978	1,685,121
1958	79,438	2,542	88,389	117,436	336,911	45,901	35,304	1,079	14,013	1,956	23,231	2,718	748,918
1959	5,893	49,481	21,137	24,990	3,950	93,884	96,525	12,186	9,732	37,039	30,030	191,756	576,603
1960	111,474	29,294	29,305	2,607	20,205	41,328	60,763	12,875	70,623	84,239	5,522	303,340	771,575
1961	90,216	42,660	131,589	61,337	13,982	3,260	8,437	1,665	5,123	253	33,293	74,111	465,926
1962	61,340	33,298	22,057	80,169	26,327	56,472	35,653	1,145	98,122	59,580	117,492	16,243	607,898
1963	34,986	1,305	25,939	18,646	10,600	1,106	7,092	277	48	10	38	77	100,124
1964	15	1,356	30,185	92,212	16,292	35,238	99	203	34,575	1,871	65,460	4,759	282,265
1965	49,492	229,759	8,492	3,969	199,932	10,096	124	81	5,655	141	0	123	507,864
1966	1,297	59,460	1,344	340,002	252,371	1,186	147	4,846	11,103	24,682	32	3,204	699,674
1967	847	1,674	9,654	259,512	140,535	172,354	43,670	83	25,630	54,082	72,262	133,408	913,711
1968	86,473	53,279	292,548	193,629	254,722	198,927	39,417	9,147	59,129	13,036	106,026	165,111	1,471,444
1969	110,736	356,113	236,512	61,336	450,623	7,811	613	48	69	6,258	4,473	56,647	1,291,239
1970	34,604	144,565	216,614	158,539	22,446	5,531	314	0	15,207	94,716	26,055	5,754	724,345
1971	4,529	16,595	7,504	598	9,322	319	5,507	50,817	2,770	253,986	8,114	503,142	863,203
1972	14,920	4,173	5,959	726	1,236	1,479	459	332	0	21,409	134,901	61,407	247,001

Table D-1d (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	76,706	101,555	366,411	303,328	37,517	100,921	1,387	593	127,819	185,260	284,350	104,957	1,690,804
1974	105,192	8,592	2,866	33,570	17,266	185,551	214	526	109,394	10,818	301,636	104,931	880,556
1975	13,804	188,133	72,166	29,465	120,509	91,715	9,647	1,760	197	42	161	374	527,973
1976	229	126	13,054	93,940	68,741	63,802	200,761	866	4,082	23,858	4,793	83,656	557,908
1977	56,949	120,395	202,724	174,136	4,541	7,489	1,004	1,339	72	0	5,378	1,215	575,242
1978	8,467	31,122	72,990	5,091	12,605	6,906	0	0	3	0	25,357	4,900	167,441
1979	188,824	96,072	139,418	101,870	281,252	128,371	7,201	13,593	470	368	1,504	81,664	1,040,607
1980	94,493	84,493	1,953	41,537	89,455	6,076	21	4	16,034	29,668	986	50,677	415,397
1981	646	1,241	22,639	3,189	108,204	263,767	3,429	177	2,620	341,325	154,028	3,311	904,576
1982	6,571	50,771	55,519	42,754	548,806	152,831	26,676	7,585	1,105	1,883	102,069	308,046	1,304,616
1983	8,116	185,468	146,793	12,880	36,939	8,146	48,075	260	16	280	694	2,417	450,084
1984	2,144	69,697	261,803	22,421	76,758	834	365	620	254	71,979	31,449	114,982	653,306
1985	18,001	71,949	97,979	42,637	70,597	11,512	3,316	34	2	6,368	66,698	100,471	489,564
1986	1,229	76,503	4,272	104,177	43,089	80,548	39,713	45	5,258	15,285	92,867	40,075	503,061
1987	47,192	45,255	56,899	3,240	5,118	7,805	5,592	342	28,939	28,635	117,525	109,637	456,179
1988	38,191	24,010	35,902	31,970	1,163	116	12,009	252	998	1,983	113,215	22,625	282,434
1989	71,398	227,282	107,320	19,659	260,133	331,823	159,651	4,850	9,308	0	0	0	1,191,424
1990	162,752	118,823	230,528	140,694	275,773	47,523	1,328	1,045	10,933	20,219	29,574	39,637	1,078,829
1991	101,988	46,542	21,708	147,425	57,051	28,593	2,735	873	2,369	117,808	114,243	326,614	967,949
1992	84,307	82,883	129,328	11,132	78,729	77,447	150,322	46,766	12,117	1,224	35,796	117,591	827,642
1993	67,464	109,997	96,524	67,540	47,101	7,602	42	0	1	114,133	49,441	150,202	710,047
1994	34,617	51,426	80,981	6,919	118,017	30,464	50,349	6,570	7,799	11,619	101,694	108,051	608,506
1995	111,362	13,454	71,717	90,958	281,952	41,884	2,828	574	3,245	483	471	1,170	620,098
1996	3,545	443	2,788	4,649	26,666	20,868	1,017	33,908	17,507	39,847	309,762	81,128	542,128
1997	14,065	293,542	111,395	186,087	8,875	26,128	1,463	859	524	6,581	3,220	98,453	751,192
1998	106,005	71,228	68,354	12,222	2,878	494	251	403	9,533	16,709	18,897	98,696	405,670
1999	45,465	16,863	34,492	27,085	11,621	11,880	2,683	26	39	50	567	8,769	159,540
2000	1,037	9,547	48,160	27,106	85,600	92,979	28,636	0	317	248	300,886	204,845	799,361
2001	130,901	248,755	283,557	73,557	14,792	37,471	3,927	252	64,091	33,344	7,217	336,760	1,234,624
Average	53,455	81,951	89,312	86,734	119,149	61,411	21,770	4,376	16,444	33,827	59,026	80,106	707,562

Table D-1e
Monthy Incremental Flows Lake Chapman to Highway 67 Bridge
Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	202	8,742	8,615	235,931	231,688	239,008	219,153	439	1,665	167	145,384	386,202	1,477,196
1941	190,882	127,112	284,409	198,896	681,487	446,119	156,233	12,142	2,710	22,824	60,643	131,249	2,314,706
1942	21,758	52,118	140,984	799,443	431,977	156,970	4,753	2,993	8,402	970	17,069	64,261	1,701,698
1943	76,019	15,525	223,173	114,305	43,959	172,349	8,568	445	949	7,015	2,839	19,591	684,737
1944	60,326	138,429	479,915	150,716	643,457	193,916	1,579	1,445	18,162	377	46,309	164,704	1,899,335
1945	286,896	365,379	1,027,891	1,064,614	88,440	459,125	156,036	6,143	12,234	288,830	25,909	4,084	3,785,581
1946	347,651	638,366	125,962	182,692	618,425	412,501	6,221	7,715	4,079	1,436	619,547	240,008	3,204,603
1947	94,095	12,368	151,227	191,000	342,355	14,901	2,668	1,731	1,910	619	64,669	349,530	1,227,073
1948	217,610	264,659	310,422	54,391	511,929	23,207	7,751	3,479	631	884	1,497	2,930	1,399,390
1949	278,580	341,022	341,359	133,859	161,567	45,632	10,153	3,973	3,972	335,828	60,244	43,448	1,759,637
1950	411,116	857,267	138,700	18,253	573,003	55,197	29,761	50,143	407,493	12,344	1,799	1,001	2,556,077
1951	31,141	370,403	50,200	20,261	41,141	228,682	32,632	2,588	6,448	6,185	17,238	37,052	843,971
1952	120,340	51,032	85,852	708,029	187,718	55,173	8,508	2,159	63	61	41,342	215,840	1,476,117
1953	98,652	138,759	129,451	191,972	701,158	4,388	32,995	3,028	7,036	722	13,365	69,644	1,391,170
1954	200,110	112,954	13,014	44,815	427,907	26,235	260	47	48	94,155	26,270	9,730	955,545
1955	14,086	51,611	132,085	187,120	25,495	3,860	30,054	10,833	21,964	54,427	592	1,056	533,183
1956	1,067	244,579	6,437	3,878	96,054	3,272	1,677	993	778	779	18,566	2,272	380,352
1957	34,014	87,287	251,641	969,093	1,155,758	578,657	1,555	3,514	59,718	130,654	690,073	62,280	4,024,244
1958	254,494	7,423	214,625	426,231	884,446	124,632	132,587	4,126	46,993	5,855	56,843	11,461	2,169,716
1959	12,859	184,062	109,185	94,598	11,334	160,865	162,574	23,936	14,087	82,841	70,106	493,484	1,419,931
1960	327,962	77,554	82,996	6,109	31,171	67,907	117,416	18,435	131,537	153,501	27,717	710,853	1,753,158
1961	221,508	128,566	281,209	225,357	29,639	54,006	44,557	6,123	9,309	3,027	52,711	241,257	1,297,269
1962	177,351	164,316	160,627	160,524	96,505	69,704	45,837	4,973	115,613	90,214	160,021	52,394	1,298,079
1963	79,034	7,732	82,230	41,812	81,169	7,425	14,333	171	52	332	1	2,135	316,426
1964	2,097	7,122	46,118	221,229	89,685	45,959	1	7,531	60,785	15,635	73,136	34,317	603,615
1965	77,901	495,686	39,499	20,722	344,691	31,116	519	946	3,716	34	45	2,428	1,017,303
1966	9,284	167,559	6,869	775,417	813,823	2,035	4,543	10,454	31,457	72,153	653	10,600	1,904,847
1967	5,781	8,527	26,693	516,564	273,862	425,225	84,533	414	31,246	75,760	256,139	304,754	2,009,498
1968	174,726	114,203	500,370	215,164	497,627	216,182	41,793	13,205	65,994	11,954	125,182	201,735	2,178,135
1969	136,340	606,377	375,195	167,431	653,814	10,138	140	1,555	7,882	1,136	9,192	66,897	2,036,097
1970	65,696	230,553	484,043	363,737	88,427	19,720	2,991	3,071	13,626	120,491	37,863	15,630	1,445,848
1971	13,388	50,770	40,492	4,792	18,263	2,754	33,976	73,545	2,299	281,583	62,327	961,769	1,545,958
1972	99,793	10,102	23,110	5,968	5,611	4,937	4,375	591	5,610	30,833	213,905	177,818	582,653

Table D-1e (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	163,049	232,580	655,442	642,762	115,303	253,077	6,121	7	136,906	246,045	644,202	291,219	3,386,713
1974	352,967	66,392	35,713	91,787	92,981	395,782	368	1,671	208,549	81,788	596,413	357,806	2,282,217
1975	61,112	574,490	267,631	128,521	343,737	137,121	13,391	5,290	75	60	3,279	1,644	1,536,351
1976	5,910	7,850	97,655	158,570	220,037	157,695	287,239	124	10,620	23,243	11,924	95,295	1,076,162
1977	86,140	267,185	434,303	381,784	23,489	19,674	665	2,082	59	66	47,709	10,755	1,273,911
1978	40,052	81,004	206,931	14,568	22,228	11,297	20	0	14	0	26,266	13,425	415,805
1979	397,391	186,255	263,655	325,844	664,750	258,939	21,971	58,534	12,726	916	9,064	245,561	2,445,606
1980	291,366	223,816	26,614	162,259	143,120	29,402	1,047	1,288	13,784	30,255	11,447	59,401	993,799
1981	4,876	22,693	38,626	11,214	258,838	525,759	37,772	160	448	439,611	201,685	7,391	1,549,073
1982	23,567	87,879	85,682	63,642	683,703	284,854	89,634	12,156	360	1,256	140,310	672,505	2,145,548
1983	19,953	234,889	270,418	47,626	67,260	20,703	59,022	22	0	25	1,387	18,626	739,931
1984	12,121	88,954	327,055	123,211	75,816	19	11	16	8	209,107	165,635	331,969	1,333,922
1985	63,885	230,927	336,636	211,529	186,081	46,140	3,168	16	1	4,308	83,491	318,784	1,484,966
1986	8,307	259,222	22,862	320,117	136,730	175,673	63,208	33	3,199	13,976	107,407	119,644	1,230,378
1987	109,904	119,089	430,356	18,883	13,850	22,310	8,151	0	30,667	33,825	306,742	654,192	1,747,969
1988	170,217	98,864	106,610	92,004	649	0	43,734	520	1,164	2,681	313,249	143,608	973,300
1989	143,310	528,296	264,141	112,394	540,076	527,641	198,507	16,891	8,527	80	161	1,502	2,341,526
1990	206,118	255,016	818,478	388,029	722,305	163,214	7,321	10,255	11,033	28,274	96,878	189,117	2,896,038
1991	344,195	210,868	114,572	375,773	261,982	37,308	5,963	4,872	5,803	212,967	272,487	781,585	2,628,375
1992	208,206	260,330	440,833	41,371	123,371	159,469	450,306	171,388	30,735	2,537	91,707	444,067	2,424,320
1993	328,395	245,924	406,584	199,738	85,689	21,281	1,208	1,223	3,089	311,643	110,773	418,175	2,133,722
1994	108,751	166,547	317,017	29,800	188,274	54,505	160,111	10,753	9,920	32,681	274,340	355,623	1,708,322
1995	363,142	90,081	177,858	271,414	506,753	63,532	7,487	1,486	16,613	1,244	2,025	4,809	1,506,444
1996	11,719	2,375	11,500	15,965	69,619	40,231	9,631	94,213	41,503	65,306	644,780	204,906	1,211,748
1997	91,907	751,429	406,351	486,269	112,826	113,345	0	7,785	448	13,824	32,157	228,907	2,245,248
1998	624,099	289,003	256,335	26,833	32,744	0	0	1,815	47,898	147,835	86,169	406,053	1,918,784
1999	183,949	119,008	242,791	120,722	72,078	26,841	7,099	9	330	6,206	1,069	17,926	798,028
2000	9,963	32,408	140,228	111,869	285,676	427,493	100,344	0	0	766	481,797	457,612	2,048,156
2001	439,726	806,973	807,173	216,269	114,546	54,325	23,556	1,361	77,735	146,916	36,305	741,433	3,466,318
Average	145,436	204,492	232,010	221,060	274,969	135,313	48,513	11,078	28,559	63,888	125,807	204,612	1,695,739

Table D-1f

Releases from Lake Chapman for Downstream Water Rights

Values in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	157	2,591	2,192	0	0	0	0	255	541	43	0	0	5,779
1941	0	0	0	0	0	0	0	1,430	0	0	4,162	0	5,592
1942	1,658	2,410	0	0	0	0	0	998	0	397	7,533	0	12,996
1943	160	2,162	0	720	0	6,315	162	0	0	64	1,138	4,401	15,122
1944	390	0	0	0	0	0	816	1,395	525	0	4,957	0	8,083
1945	0	0	0	0	0	0	0	91	0	0	2,935	22	3,048
1946	0	0	0	0	0	0	452	0	215	169	0	0	836
1947	0	363	0	0	0	5,195	2	2,457	306	210	0	0	8,533
1948	0	0	0	0	0	2,777	0	48	0	18	0	1,983	4,826
1949	0	0	0	0	0	0	0	0	898	0	229	3,000	4,127
1950	0	0	2,090	1,651	0	0	0	0	0	124	5	21	3,891
1951	772	0	574	266	0	0	0	0	0	0	1,106	271	2,989
1952	3,628	1,724	0	0	0	0	0	0	0	0	0	0	5,352
1953	0	1,046	0	0	0	6	0	0	4	109	3,947	0	5,112
1954	0	0	102	0	0	551	0	0	0	0	0	509	1,162
1955	1,199	0	0	0	0	45	0	0	767	0	0	0	2,011
1956	0	0	9	360	0	1,337	0	0	0	0	2,310	1,873	5,889
1957	2,989	0	0	0	0	0	365	0	0	0	0	0	3,354
1958	0	764	0	0	0	0	0	56	0	444	0	660	1,924
1959	994	0	0	0	2,056	0	0	0	0	0	0	0	3,050
1960	0	0	0	2,046	0	0	0	0	0	0	691	0	2,737
1961	0	0	0	0	0	8,880	0	1,288	0	41	0	0	10,209
1962	0	0	0	0	0	0	0	2,016	0	0	0	0	2,016
1963	0	187	0	0	0	1,064	0	20	0	0	0	0	1,271
1964	0	67	0	0	0	0	0	0	0	0	0	1,096	1,163
1965	0	0	1,271	520	0	0	18	0	470	17	632	0	2,928
1966	646	0	793	0	0	41	444	0	0	0	48	613	2,585
1967	155	62	1,830	0	0	0	0	68	0	0	0	0	2,115
1968	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	2,310	0	0	0	529	2,251	0	5,090
1970	0	0	0	0	0	3,228	0	0	0	0	0	1,453	4,681
1971	1,008	0	3,570	31	45	67	244	0	0	0	735	0	5,700
1972	0	621	5,298	205	680	733	0	0	152	0	0	0	7,689

Table D-1f (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	0	0	0	0	0	0	649	188	0	0	0	0	837
1974	0	3,623	8,535	0	0	0	47	463	0	0	0	0	12,668
1975	0	0	0	0	0	0	0	165	0	0	0	141	306
1976	0	34	5,205	0	0	0	0	392	0	0	3,258	0	8,889
1977	0	0	0	0	1,741	5,806	239	2,258	770	0	4,705	756	16,275
1978	4,510	0	0	1,998	0	4,619	0	0	0	0	0	0	11,127
1979	0	0	0	0	0	0	0	0	391	99	317	0	807
1980	0	0	186	0	0	837	0	0	0	0	124	0	1,147
1981	64	40	0	1,201	0	0	0	33	0	0	0	736	2,074
1982	1,079	0	0	0	0	0	0	0	451	0	0	0	1,530
1983	1,668	0	0	0	0	2,908	0	46	0	378	739	293	6,032
1984	282	0	0	0	0	205	0	0	0	0	0	0	487
1985	0	0	0	0	0	420	0	0	0	0	0	0	420
1986	84	0	244	0	0	0	0	0	0	0	0	0	328
1987	0	0	0	640	5,295	581	0	0	0	0	0	0	6,516
1988	0	0	0	0	6	89	0	0	2,074	8	0	0	2,177
1989	0	0	0	0	0	0	0	0	0	74	202	40	316
1990	0	0	0	0	0	0	0	1,368	0	0	0	0	1,368
1991	0	0	0	0	0	0	30	0	0	0	0	0	30
1992	0	0	0	2,681	0	0	0	0	0	0	0	0	2,681
1993	0	0	0	0	0	1,539	2,828	1,024	0	0	0	0	5,391
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	1,650	0	0	1,869	0	3,519
1996	3,886	2,037	3,611	6,363	0	0	0	0	0	0	0	0	15,897
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	409	286	573	301	158	799	102	286	122	44	708	288	4,076

Table D-2a
Lake Jim Chapman Evaporation Rates
Values in Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	0.03	-0.07	0.15	-0.14	-0.06	0.06	0.23	0.38	0.46	0.24	-0.29	-0.07	0.93
1941	0.05	-0.01	0.17	-0.15	0.29	-0.13	0.17	0.30	0.33	-0.16	0.10	-0.03	0.91
1942	-0.06	0.05	0.12	-0.09	0.17	0.08	0.43	0.28	0.11	0.13	0.16	-0.13	1.23
1943	0.10	0.16	-0.12	0.18	-0.04	0.36	0.48	0.67	0.12	0.15	0.13	-0.15	2.04
1944	-0.11	-0.16	0.02	0.04	-0.02	0.41	0.40	0.21	0.35	0.28	-0.18	-0.11	1.12
1945	0.01	-0.14	-0.27	0.05	0.19	-0.01	0.08	0.19	0.18	0.12	0.14	0.04	0.57
1946	-0.22	0.05	-0.04	0.00	-0.20	0.24	0.33	0.32	0.19	0.25	-0.18	-0.04	0.69
1947	-0.05	0.17	-0.20	-0.15	0.07	0.27	0.54	0.36	0.30	0.23	-0.09	-0.10	1.37
1948	0.01	-0.04	-0.07	0.31	0.18	0.39	0.38	0.63	0.57	0.23	0.17	0.08	2.83
1949	-0.34	-0.01	-0.09	-0.05	0.10	0.14	0.25	0.33	0.22	-0.24	0.25	-0.06	0.50
1950	-0.18	0.16	0.12	-0.03	0.02	0.20	-0.07	0.16	0.08	0.28	0.29	0.20	1.24
1951	-0.09	-0.11	0.13	0.16	0.17	0.20	0.32	0.66	-0.09	0.18	0.07	0.05	1.65
1952	0.05	-0.02	-0.04	-0.11	0.08	0.47	0.28	0.69	0.61	0.57	-0.21	-0.17	2.20
1953	0.05	-0.03	-0.03	-0.02	-0.09	0.56	-0.08	0.28	0.36	0.27	-0.06	-0.08	1.14
1954	-0.12	0.24	0.31	0.16	-0.15	0.47	0.67	0.73	0.34	-0.20	0.15	-0.02	2.58
1955	-0.03	-0.04	0.17	0.06	0.04	0.43	0.36	0.18	0.23	0.36	0.28	0.13	2.17
1956	0.01	-0.20	0.28	0.22	0.28	0.43	0.65	0.72	0.63	0.26	-0.15	0.04	3.17
1957	-0.08	-0.02	-0.11	-0.03	-0.08	0.23	0.52	0.38	-0.14	0.02	-0.14	-0.01	0.56
1958	-0.06	0.05	-0.05	-0.06	0.31	0.15	0.25	0.24	-0.05	0.15	-0.05	-0.01	0.87
1959	0.04	-0.06	0.22	0.18	0.14	-0.04	-0.05	0.30	0.28	-0.10	0.11	-0.07	0.94
1960	-0.06	-0.02	0.11	0.23	0.22	0.24	0.24	0.18	0.02	0.05	0.12	-0.14	1.20
1961	0.11	-0.07	0.01	0.32	0.11	-0.01	0.15	0.34	0.14	0.18	-0.21	-0.09	0.97
1962	-0.12	0.05	0.05	0.06	0.37	-0.08	0.35	0.43	-0.04	-0.06	-0.01	0.04	1.03
1963	0.05	0.14	0.20	0.06	0.16	0.34	0.18	0.57	0.40	0.47	0.11	-0.01	2.67
1964	0.03	-0.02	-0.10	-0.05	0.11	0.39	0.62	0.16	-0.19	0.25	-0.04	0.07	1.24
1965	0.02	0.01	0.07	0.29	0.06	0.24	0.54	0.50	0.05	0.24	0.02	0.02	2.05
1966	-0.13	-0.19	0.27	-0.12	0.29	0.42	0.35	-0.04	0.03	0.18	0.22	-0.08	1.21
1967	0.13	0.09	0.20	-0.10	-0.21	0.63	0.20	0.48	-0.10	0.08	0.17	-0.04	1.53
1968	-0.12	0.05	0.04	0.10	0.04	0.06	0.28	0.45	-0.07	0.20	-0.09	0.03	0.95
1969	0.04	0.12	0.01	0.13	0.10	0.39	0.61	0.51	0.21	-0.03	0.15	-0.13	2.10
1970	0.05	-0.10	0.13	0.05	0.25	0.29	0.52	0.44	-0.08	-0.01	0.13	0.08	1.74
1971	0.09	0.02	0.32	0.31	0.11	0.54	0.15	0.13	0.16	0.00	0.10	-0.25	1.68

Table D-2a (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	0.02	0.18	0.25	0.24	0.25	0.29	0.48	0.42	0.06	-0.30	-0.09	0.00	1.81
1973	-0.06	0.02	-0.02	-0.02	0.16	-0.01	0.30	0.46	-0.25	-0.09	0.15	0.04	0.68
1974	0.03	0.18	0.26	0.26	0.21	0.32	0.53	0.04	-0.29	-0.14	0.10	0.07	1.57
1975	0.01	0.24	0.10	0.25	0.00	0.21	0.33	0.37	0.29	0.38	0.09	-0.01	2.26
1976	0.22	0.19	-0.09	0.05	-0.01	0.14	0.08	0.47	0.04	-0.05	0.12	0.16	1.32
1977	-0.07	0.15	0.19	0.15	0.27	0.32	0.50	0.23	0.31	0.31	-0.09	0.19	2.45
1978	-0.10	-0.04	0.09	0.26	0.05	0.40	0.66	0.55	0.34	0.42	-0.41	-0.07	2.16
1979	0.04	-0.09	0.00	0.18	0.05	0.40	0.15	0.20	0.17	0.13	0.10	-0.08	1.25
1980	-0.03	0.14	0.17	0.17	0.06	0.28	0.74	0.72	-0.08	0.15	0.08	0.07	2.46
1981	0.15	0.09	0.13	0.21	-0.18	0.42	0.37	0.45	0.33	-0.40	0.14	0.20	1.91
1982	-0.06	-0.03	0.16	0.13	0.00	0.04	0.30	0.31	0.41	0.05	-0.31	-0.24	0.77
1983	0.07	0.07	0.12	0.24	-0.07	0.12	0.41	0.37	0.41	0.08	0.03	-0.10	1.75
1984	-0.03	0.01	0.15	0.26	0.02	0.41	0.36	0.43	0.27	-0.35	0.10	-0.05	1.60
1985	0.01	-0.12	0.03	0.03	0.15	0.29	0.37	0.62	0.32	-0.16	-0.04	0.03	1.54
1986	0.19	0.01	0.25	-0.06	0.00	0.11	0.48	0.51	0.23	-0.09	-0.16	-0.05	1.42
1987	0.02	-0.07	0.20	0.39	-0.10	0.03	0.30	0.50	-0.02	0.10	0.01	-0.12	1.24
1988	0.12	0.04	-0.03	0.24	0.40	0.45	0.22	0.33	0.17	-0.03	-0.18	-0.04	1.69
1989	-0.01	-0.04	0.01	0.29	-0.24	-0.03	0.06	0.35	0.18	0.25	0.25	0.17	1.25
1990	-0.30	0.00	-0.11	0.04	-0.12	0.39	0.21	0.37	0.05	-0.02	-0.13	-0.12	0.26
1991	0.03	0.02	0.21	-0.11	0.06	0.32	0.38	0.30	0.20	-0.11	0.13	0.25	1.67
1992	0.16	0.08	0.25	0.15	0.46	0.01	0.12	0.44	0.03	0.31	-0.12	-0.06	1.84
1993	0.08	0.17	0.15	0.32	0.06	0.25	0.85	0.56	0.23	0.04	0.04	0.20	2.96
1994	0.06	0.07	0.22	0.04	0.11	0.35	0.24	0.35	0.33	-0.05	0.09	0.03	1.84
1995	0.17	0.01	0.13	0.13	0.09	0.31	0.33	0.50	0.00	0.36	0.21	-0.03	2.21
1996	0.05	0.39	0.14	0.22	0.23	0.16	-0.06	-0.05	0.00	0.11	-0.01	-0.02	1.14
1997	0.09	0.14	0.24	0.19	0.08	0.39	0.46	0.23	0.44	-0.09	-0.02	0.07	2.22
1998	-0.09	-0.01	0.04	0.27	0.31	0.52	0.67	0.48	0.06	-0.01	0.07	0.11	2.41
1999	0.13	0.16	0.02	0.16	0.01	0.19	0.48	0.61	0.27	0.25	0.17	0.08	2.53
2000	-0.09	-0.04	-0.11	0.11	0.01	0.29	0.45	0.65	0.41	0.04	0.24	-0.05	1.91
2001	-0.31	-0.04	-0.01	0.18	-0.10	0.21	0.41	0.12	-0.40	0.02	-0.06	-0.24	-0.23
Average	-0.01	0.03	0.08	0.11	0.08	0.26	0.35	0.39	0.16	0.09	0.03	-0.01	1.56

Table D-2b
Lake Wright Patman Evaporation Rates
Values in Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1940	0.02	-0.04	0.06	-0.14	0.02	0.20	0.08	0.29	0.38	0.12	-0.32	0.10	0.77
1941	0.26	-0.04	-0.03	-0.33	0.63	0.27	0.32	0.28	0.18	0.03	0.08	-0.07	1.58
1942	0.04	0.09	0.12	-0.21	0.38	0.21	0.46	-0.03	0.14	0.07	0.14	-0.25	1.15
1943	0.19	0.14	0.07	0.25	-0.18	0.43	0.42	0.56	0.15	0.00	0.14	-0.18	2.00
1944	-0.11	-0.35	0.19	-0.04	-0.28	0.57	0.40	0.08	0.33	0.32	-0.23	-0.44	0.44
1945	0.35	-0.24	-0.15	1.45	0.10	0.10	0.10	0.21	0.10	0.16	0.07	0.04	2.30
1946	-0.26	0.16	-0.17	0.03	-0.38	0.49	0.32	0.15	0.28	0.16	-0.11	0.14	0.82
1947	0.01	0.12	0.00	-0.07	0.10	0.20	0.47	0.23	0.20	0.11	-0.25	-0.14	0.97
1948	-0.02	-0.12	0.04	0.11	-0.18	0.36	0.35	0.44	0.48	0.06	-0.06	-0.04	1.42
1949	-0.72	-0.03	0.15	0.09	0.27	-0.04	0.06	0.30	0.25	-0.45	0.32	-0.12	0.09
1950	-0.16	0.13	0.12	-0.07	-0.19	0.23	-0.12	0.29	-0.12	0.18	0.22	0.17	0.67
1951	-0.15	0.05	0.22	-0.05	0.20	-0.19	0.20	0.54	-0.24	0.09	-0.03	0.04	0.66
1952	0.05	0.04	-0.06	0.14	0.07	0.39	0.31	0.50	0.57	0.47	-0.49	-0.06	1.93
1953	-0.05	0.23	-0.06	-0.36	0.38	0.50	-0.11	0.34	0.29	0.29	-0.02	-0.14	1.29
1954	-0.18	0.19	0.20	0.01	-0.11	0.47	0.46	0.70	0.37	-0.43	0.03	-0.15	1.55
1955	-0.06	-0.09	0.07	0.14	0.05	0.30	0.21	0.03	0.02	0.07	0.24	0.06	1.04
1956	-0.02	-0.12	0.06	0.01	0.12	0.15	0.31	0.35	0.29	0.11	-0.12	0.00	1.15
1957	-0.20	-0.17	-0.18	-0.25	0.41	0.24	0.17	0.21	-0.16	-0.24	-0.16	-0.09	-0.42
1958	-0.05	0.04	-0.11	-0.45	0.40	-0.07	0.05	-0.19	-0.13	-0.04	-0.20	0.04	-0.72
1959	0.01	-0.14	0.10	0.03	0.00	0.11	0.01	0.31	0.17	0.04	0.04	-0.01	0.66
1960	-0.10	-0.08	0.12	0.29	0.15	0.10	0.37	0.18	0.02	0.12	0.06	-0.09	1.14
1961	0.10	-0.09	-0.17	0.42	0.17	-0.12	-0.04	0.22	0.10	0.00	-0.30	-0.13	0.17
1962	-0.13	-0.03	0.15	0.09	0.40	0.00	0.37	0.43	-0.15	-0.29	-0.12	0.06	0.78
1963	0.04	0.15	0.07	-0.07	0.23	0.24	0.05	0.34	0.32	0.39	-0.03	-0.08	1.63
1964	0.07	-0.05	-0.06	-0.18	0.27	0.34	0.39	0.01	-0.21	0.31	-0.10	0.01	0.80
1965	-0.02	-0.25	0.08	0.31	-0.14	0.27	0.40	0.38	0.05	0.25	0.07	0.02	1.44
1966	-0.14	-0.14	0.28	-0.45	0.15	0.52	0.23	-0.10	0.03	0.04	0.08	-0.23	0.26
1967	0.13	0.06	0.23	-0.19	-0.31	0.21	0.21	0.39	0.01	0.05	0.06	-0.30	0.56
1968	-0.15	0.09	-0.08	0.00	-0.36	-0.12	0.24	0.31	-0.17	0.06	-0.24	-0.06	-0.49
1969	-0.15	-0.03	0.07	0.35	-0.06	0.35	0.49	0.53	0.22	-0.01	-0.03	-0.22	1.52
1970	0.15	-0.11	0.05	-0.06	0.23	0.27	0.33	0.12	0.25	-0.16	0.03	0.02	1.13
1971	0.09	-0.04	0.18	0.22	0.11	0.50	-0.26	0.12	0.27	0.06	-0.05	-0.48	0.72

Table D-2b (cont.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	-0.02	0.21	0.22	0.29	0.26	0.21	0.24	0.42	0.00	-0.25	-0.27	-0.13	1.17
1973	-0.08	0.02	-0.09	-0.12	0.26	-0.09	0.22	0.38	-0.28	-0.28	-0.10	0.17	0.01
1974	-0.15	0.21	0.29	0.38	0.13	-0.08	0.33	-0.01	-0.47	0.04	-0.22	-0.01	0.44
1975	0.15	0.09	0.08	0.12	0.06	0.14	0.28	0.31	0.25	0.26	-0.01	-0.07	1.69
1976	0.15	0.09	-0.10	0.11	-0.13	0.09	0.22	0.45	-0.10	-0.11	0.05	-0.09	0.62
1977	-0.08	0.10	-0.06	0.22	0.33	0.24	0.34	0.26	0.13	0.26	-0.24	0.09	1.58
1978	-0.15	0.00	0.07	0.26	0.18	0.43	0.56	0.50	0.24	0.29	-0.61	-0.12	1.63
1979	-0.15	-0.13	-0.05	0.04	-0.12	0.19	-0.15	0.29	-0.02	0.06	0.07	0.02	0.04
1980	-0.03	0.20	0.23	0.21	0.06	0.21	0.65	0.61	-0.09	0.07	0.01	0.06	2.19
1981	0.14	-0.05	0.08	0.27	-0.34	-0.01	0.06	0.21	0.27	-0.51	0.07	0.20	0.40
1982	-0.09	-0.05	0.16	-0.01	-0.25	-0.19	0.25	0.29	0.31	-0.09	-0.50	-0.40	-0.58
1983	0.07	0.07	0.07	0.19	0.04	0.10	0.17	0.35	0.34	0.12	-0.13	-0.19	1.20
1984	0.00	-0.10	-0.08	0.21	-0.06	0.36	0.06	0.17	0.00	-0.77	-0.13	-0.12	-0.44
1985	0.02	-0.14	-0.09	0.04	0.05	0.15	0.25	0.51	0.19	-0.20	-0.33	-0.03	0.43
1986	0.25	-0.06	0.20	-0.20	0.03	-0.02	0.42	0.42	-0.18	-0.08	-0.34	-0.03	0.39
1987	0.05	-0.15	0.01	0.39	0.12	0.13	0.16	0.43	0.12	-0.02	-0.59	-0.23	0.43
1988	0.17	0.04	0.03	0.22	0.40	0.42	0.08	0.10	0.27	-0.10	-0.58	-0.12	0.93
1989	-0.01	-0.16	0.25	0.27	-0.14	-0.16	0.00	0.13	0.24	0.16	0.19	0.12	0.90
1990	-0.36	-0.03	-0.17	0.00	-0.36	0.23	0.14	0.39	0.04	-0.28	-0.18	-0.24	-0.83
1991	-0.01	-0.03	0.21	-0.01	0.27	0.25	0.22	0.10	0.06	-0.31	-0.16	-0.02	0.57
1992	-0.02	0.02	0.13	0.06	0.06	-0.30	-0.17	0.44	-0.26	0.11	-0.31	-0.09	-0.34
1993	0.01	-0.11	0.16	-0.01	-0.04	0.18	0.55	0.21	0.14	-0.54	-0.11	-0.01	0.43
1994	-0.12	-0.06	0.13	0.11	-0.22	0.15	-0.05	0.29	0.36	-0.40	-0.15	-0.13	-0.08
1995	0.28	0.11	0.11	-0.10	-0.06	0.18	0.26	0.37	-0.01	0.19	0.06	-0.06	1.34
1996	0.03	0.14	0.05	0.10	0.06	-0.14	-0.19	-0.05	-0.11	-0.07	0.05	0.05	-0.07
1997	0.01	-0.14	0.25	-0.32	0.27	0.04	0.28	0.10	0.18	-0.28	-0.19	-0.23	-0.03
1998	0.14	-0.08	0.12	0.17	0.11	0.39	0.37	0.11	-0.34	-0.19	-0.16	-0.03	0.59
1999	-0.12	0.24	0.01	0.09	0.08	0.14	0.44	0.40	0.14	0.08	0.08	-0.16	1.41
2000	-0.20	-0.10	-0.09	0.02	-0.08	0.32	0.50	0.62	0.23	0.18	-0.65	0.03	0.79
2001	0.18	-0.14	0.23	0.21	-0.11	0.06	0.13	0.17	-0.38	-0.37	-0.17	-0.17	-0.37
Average	-0.02	-0.01	0.06	0.07	0.06	0.18	0.22	0.28	0.09	-0.02	-0.11	-0.07	0.73

Table D-3
Lake Jim Chapman Area Capacity Relationship

Elevation (Ft- NVGD)	**Capacity** (Ac-Ft)	**Area** (Acres)
386	0	0
390	13	7
400	892	447
405	5,970	1,689
410	16,888	2,657
415.5	37,000	5,084
418	51,017	5,900
420	63,405	6,525
424	94,130	8,625
426	112,463	9,700
430	155,643	11,880
432	180,583	13,100
436	239,190	16,400
438	273,560	17,940
440	310,813	19,305
444	392,485	21,530
446.2	441,400	22,740
450	531,608	24,885
452.8	603,670	26,563
455	665,558	27,935

Table D-4
Lake Wright Patman Area Capacity Relationship

Elevation (Ft-MSL)	Capacity (Ac-Ft)	Area (Acres)
194	0	0
195	1	1
196	3	3
197	7	5
198	13	9
199	26	16
200	47	27
201	80	42
202	134	67
203	218	104
204	350	163
205	550	243
206	863	415
207	1,500	913
208	2,723	1,547
209	4,577	2,182
210	7,204	3,157
211	10,924	4,288
212	15,791	5,448
213	21,839	6,668
214	29,195	8,024
215	38,095	9,834
216	48,861	11,718
217	61,615	13,815
218	76,348	15,611
219	92,775	17,237
220	110,900	18,994
221	130,870	21,013
222	153,000	23,226
223	177,220	25,095
224	203,250	26,980
225	231,540	28,297
226	261,140	29,614
227	292,070	30,931
228	324,310	32,248
229	357,870	33,565
230	395,420	38,600
231	435,020	40,600
232	476,620	42,600
233	520,270	44,700
234	566,070	46,900

Table D-4
(cont.)

Elevation (Ft-MSL)	Capacity (Ac-Ft)	Area (Acres)
235	614,120	49,200
236	664,370	51,300
237	716,770	53,500
238	771,370	55,700
239	828,270	58,100
240	887,570	60,500
241	949,320	63,000
242	1,013,620	65,600
243	1,080,520	68,200
244	1,150,070	70,900
245	1,222,320	73,600
246	1,297,320	76,400
247	1,375,170	79,300
248	1,455,920	82,200
249	1,539,570	85,100
250	1,626,170	88,100
251	1,715,870	91,300
252	1,808,770	94,500
253	1,904,870	97,700
254	2,004,270	101,100
255	2,107,070	104,500
256	2,213,320	108,000
257	2,322,970	111,300
258	2,435,970	114,700
259	2,552,320	118,000
260	2,671,970	121,300
261	2,795,120	125,000
262	2,921,970	128,700
263	3,052,570	132,500
264	3,187,070	136,500
265	3,325,620	140,600
266	3,468,270	144,700
267	3,615,020	148,800
268	3,765,920	153,000
269	3,921,020	157,200
270	4,080,270	161,300
271	4,243,720	165,600
272	4,411,520	170,000
273	4,583,620	174,200
274	4,760,020	178,600
275	4,940,770	182,900
276	5,125,920	187,400
277	5,315,570	191,900

Table D-4
(cont.)

Elevation (Ft-MSL)	Capacity (Ac-Ft)	Area (Acres)
278	5,509,770	196,500
279	5,708,570	201,100
280	5,912,020	205,800
281	6,120,070	210,300
282	6,332,720	215,000
283	6,550,170	219,900
284	6,772,370	224,500
285	6,999,420	229,600
286	7,231,270	234,100
287	7,467,670	238,700
288	7,708,670	243,300
289	7,954,270	247,900
290	8,204,420	252,400